Ocena sprememb obalne črte v okrožju Can Gio v Hošiminhu z geoprostorsko tehnologijo

Shoreline variation in Can Gio District, Ho Chi Minh City, Vietnam from geospatial technology

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IZVLEČEK

Can Gio je obalno okrožje južno od mesta Hošiminh (HCMC) v Vietnamu. Območje se že od nekdaj spopada s težavami zaradi spreminjanja obalne črte, ki vpliva na življenje ljudi in ekosisteme. V članku so predstavljeni rezultati uporabe geoprostorskih tehnologij za oceno sprememb obalne črte v prostoru, pri čemer se določa stopnja povečanja obrežja in erozije za preiskovano območje v letih 1998, 2009 in 2019. Za določanje obrežja iz satelitskih slikovnih podatkov Landsat se uporablja tehnika ločevanja vode in kopnega na podlagi modificiranega indeksa normirane razlike v vodi (MNDWI). Za izračun stopnje spremembe smo uporabili modul DSAS (Digital Shoreline Analysis System). Kot kažejo rezultati, je okrožje Can Gio v enaindvajsetih letih, od 1998 do 2019, izgubilo približno 500 ha zemljišč. Erozijsko območje je največje v občini Thanh An in predstavlja 29 % erozijskega območja celotnega okrožja. Najvišja stopnja erozije, do 18,2 m na leto, je bila zabeležena v ustju reke Nga, najvišja stopnja rasti 29,2 m/leto, pa je bila zabeležena na levem bregu reke Dongh Tranh. Rezultati raziskave so uporabni za ekološko in okoljsko upravljanje na obalnih območjih, ki se spopadajo s tveganjem za spremembe in naraščanjem morske gladine.

ABSTRACT

Can Gio is a coastal district in the Southern coastal area of Ho Chi Minh City (HCMC), Vietnam. This area has been and is being affected by the problem of shoreline variations, affecting human life and ecosystems. The article presents the results of applying geospatial technologies to evaluate the shoreline variations in space, thereby determining the rate of shoreline accretion and erosion for the study area in 1998, 2009 and 2019. The technique of separating water and land based on the Modified Normalized Difference Water Index (MNDWI) is used to extract the shoreline from Landsat satellite image data. We used the Digital Shoreline Analysis System (DSAS) module to calculate the variation rate. The results show that, within 21 years, from 1998 to 2019, Can Gio District has lost about 500 ha of land. Thanh An Commune has the largest erosion area, accounting for 29% of the erosion area of the whole district. The highest erosion rate of up to 18,2 m/year was recorded in the Nga Bay River area, and the highest accretion rate of 29,2 m/year was recorded on the left bank of Dong Tranh River. This research result supports ecological and environmental management in coastal areas facing the risk of climate change and rising sea levels.

KLJUČNE BESEDE

spremembe obalne črte, erozija, povečanje, geoprostorska tehnologija

KEY WORDS

shoreline variation, erosion, accretion, geospatial technology

1 Introduction

Shoreline variation is the change in the position of the shoreline over space and time. There are two types of shoreline variation: accretion, the phenomenon of the shoreline gradually encroaching towards the water, and erosion, the phenomenon of the shoreline gradually encroaching towards the mainland. The cause of shoreline variation is determined to be the combined influence of natural processes (morphology, geological structure, hydrology, etc.) and artificial processes (sand mining, waterway transport, dam construction, upstream reservoirs, etc.) (Thu et al., 2018). Erosion of river mouths and coastlines causes dire consequences: direct damage to life, property, infrastructure and land, causing environmental degradation and other environmental disasters. The sediment released from the erosion process causes turbidity and organic contamination of water bodies. In many cases, the erosion of mud and sand in one area is the cause of accretion in another area. Although the accretion process creates valuable alluvial flats for many regions, in many places, it also becomes a severe disaster, causing accretion of shipping channels, ports, and estuaries, obstructing traffic, reducing flood drainage capacity, causing widespread flooding, and freshwater of lagoons and bays. In Vietnam, shoreline variation, especially erosion in all three regions of the North, Central and South, is highly complex and causes severe damage to life and property, leaving long-term consequences for the economy, society and ecological environment. In addition, the accretion process also causes severe damage to economic development, especially waterways and seaports. The negative impacts of shoreline variation have created an urgent need to monitor, supervise and assess the level of variation in river and marine coastal areas to issue timely warnings and minimize damage.

The development of geospatial technologies has provided an alternative to on-site survey methods that are too labour-intensive and costly. Studies applying geospatial technologies in monitoring shoreline variation are often based on shoreline position changes using land and water separation techniques from satellite image data. However, the differences in studies are mainly based on the water separation formula used. In 1996, McFeeters et al. introduced the Normalized Difference Water Index (NDWI) as an index used to separate water from satellite image data. The index is a combination of the GREEN band and the near-infrared (NIR) band according to the formula (GREEN - NIR) / (GREEN + NIR); the index results range from -1 to +1. In this study, McFeeters et al. proposed a threshold value of 0 for water separation; pixels with NDWI values greater than 0 are classified as water, and vice versa is not water. This method has the advantage of detecting water in areas without built-up land (Rokni et al., 2014). However, the results when using NDWI are often confused between built-up land and water surface (Xu, 2006). To overcome the above shortcomings of NDWI, Xu (2006) proposed the Modification of Normalised Difference Water Index (MNDWI) by using a shortwave infrared (SWIR) band instead of the NIR band used in NDWI. Xu's MNDWI has the advantage of extracting water in areas where the land is mainly built-up land or alluvial area (Xu, 2006) but has the disadvantage of detecting water areas with high silt concentration (Sun et al., 2012) and in sea areas around ports (Yang et al., 2015). In 2007, Alesheikh et al. proposed using the Band Ratio formula with the GREEN/NIR and GREEN/SWIR ratios to separate water. Subsequently, the study of Shen et al. (2010) introduced the Water Ratio Index (WRI) based on the special spectral characteristics of water to separate the land and water. Specifically, the index is calculated by the formula (GREEN + RED) / (NIR + SWIR); the water part in the formula has a value greater than 1. In 2014, Feyisa et al. proposed the Automatic Water

Extraction Index (AWEI) to improve the accuracy in shadow areas and detect non-water dark surface disturbances that the above techniques often do not classify well (Feyisa et al., 2014). AWEI also has the advantage of detecting coastal muddy water bodies (Li & Gong, 2016). However, this method still has weaknesses in detecting waters around ports (Yang et al., 2015) and is not as good as the NDWI and MNDWI methods in detecting waters in areas without built-up land (Rokni et al., 2014). It can be seen that each of the above methods has certain advantages and limitations in detecting shorelines; scientists have also conducted many comparative studies on the effectiveness of each method (Lai et al., 2020; Duru, 2017; Rokni et al., 2014; Wicaksono & Wicaksono, 2019), but based on the research results, it can be seen that, depending on the characteristics of the terrain and geomorphology, each method is suitable for a particular area. Therefore, determining the appropriate shoreline extraction method for the research area before conducting the research is extremely important.

Regarding the application of the Digital Shoreline Analysis System (DSAS) module, there have been many studies on shoreline variation worldwide using this module to calculate, evaluate and forecast shoreline variation. Some outstanding studies applying the DSAS module are as follows: the study of Bouchahma et al. (2012) analyzed the shoreline variation of a part of the coastal strip of Djerba Island (Tunisia) from 1984 to 2009; Duru (2017) examined the shoreline variation of Sapanca Lake (Turkey); Oyedotun et al. (2018) studied the variation of the Mazatlán coastline (Mexico); and Ramdhan et al. (2020) analyzed shoreline variation on Cemara Besar Island (Indonesia).

In Vietnam, monitoring shoreline variation has been a matter of particular interest to scientists for a long time. Many studies on shoreline variation analysis have been conducted, such as Nguyen et al. (2011) on shoreline variation in the Mekong River (the section flowing through Vietnam); Diem et al. (2013) assessing the erosion and accretion situation in the coastal areas of Ca Mau and Bac Lieu provinces; Tran Thi et al. (2014) assessing variation in the mangrove shoreline of Ca Mau cape; Binh & Duong (2018) analyzing shoreline variation in Da Nang city; and Duyen et al. (2024) analyzing and assessing the erosion and accretion process of the Western coast of the Mekong Delta from Ca Mau cape to Kien Giang. In general, the results from the studies demonstrate the effectiveness of remote sensing and satellite image analysis in monitoring shoreline variation.

2 Study area

Can Gio District has an area of 704,5 km2, is the last district in the Southeast direction of Ho Chi Minh City (HCMC), Vietnam, with coordinates from 106°46'12" to 107°00'50" East longitude and from 10°22'14" to 10°40'00" North latitude (Figure 1). The district's terrain is mainly mangrove swamps; the average land surface elevation is low (0,6-0,7 m), so tides often flood many areas. The funnel-shaped estuaries create Can Gio Bay, which is concave into the mainland (Hai & Tuyen, 2011). The district's climate is typical of the equatorial tropical monsoon, with two distinct seasons: the rainy season from May to October and the dry season from November to April of the following year. The average temperature of the months of the year is from 25-29 degrees Celsius. The average annual rainfall is from 1.000-1.400 mm. In the rainy season, the lowest monthly rainfall is about 100 mm, and the highest monthly rainfall is about 240 mm. The main wind direction in the rainy season is West-Southwest, and the main wind direction in the dry season is North-Northeast (Can Gio District People's Committee, 2019). Because

Can Gio District is located in the coastal area of Southeast Vietnam, this area is dominated by the East Sea tide, and according to the semi-diurnal tide regime, the tides are quite complicated. Except for a few days in the month when there is only one tide per day, the rest of the days have two tides per day (Hai & Tuyen, 2011). Can Gio has a complex river system, accounting for 32% of the district's total area, and most rivers usually flow in a Southeast direction (Loi, 2011). Formed downstream of the Dong Nai and Saigon River systems, the Can Gio mangrove forest is a complex of terrestrial and aquatic flora and fauna. The mangrove forest cover accounts for nearly half of the district's natural area, playing many vital roles for HCMC and neighboring areas, such as regulating the climate, providing oxygen, being a settling tank filtering wastewater from upstream with many industrial wastes and pesticides before flowing into the sea, limiting natural disasters caused by storms and strong winds from the sea.

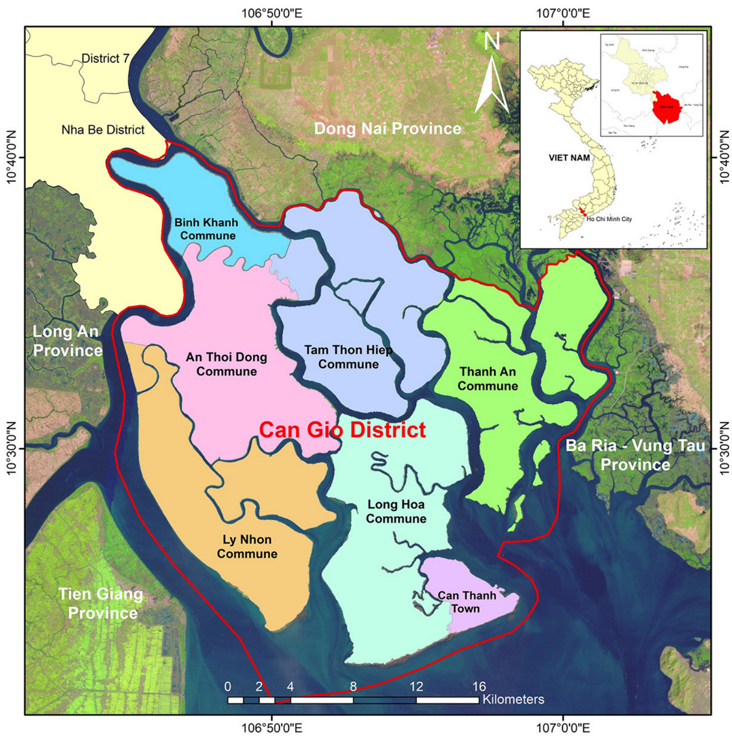

Figure 1: Geographical location of Can Gio District.

According to the results of Nam & Tri's (2014) study, from 1953 to 2010, the total erosion rate in this area was 5.126 ha (rate of 89,9 ha/year), while the accretion rate was 316 ha (rate of 5,5 ha/year), with only one accretion location on the Dong Tranh River bank and six eroded locations. The two locations where severe erosion occurred were Thanh An Commune and Can Thanh Town. Currently, the access to Saigon port (belonging to HCMC) is through Can Gio District via Long Tau and Nga Bay rivers (belonging to the river system of Can Gio District). The movement of large ships has caused significant erosion, although the mangrove forest population has largely minimized the impact on the riverbank area. Along with the impacts of climate change, storms are becoming more potent and destructive, and combined with rising sea levels, the problem of erosion in Can Gio will undoubtedly become more and more serious (Hai & Tuyen, 2011).

3 Data and methods

3.1 Data

The main data used in this study are satellite images collected from Landsat-5 equipped with Thematic Mapper (TM) sensor and Landsat-8 equipped with Operational Land Imager (OLI) sensor and Thermal Infrared Sensor (TIRS). The selected images are during the dry season (January and February). This is the time when the river water level is not affected by rain and floods, the cloud cover is less than 10% of the study area's coverage, and the cloud position does not cover the boundary between land and water to be extracted. Can Gio District is not fully covered in a single Landsat image scene, so multiple contiguous images need to be collected and merged to cover the entire district. To avoid too much difference in status between regions, the adjacent images were selected with the closest dates (Table 1). Additionally, to minimize the impact of tides on shoreline determination, we selected and collected satellite images taken during the low tide period at the study area. This approach helps reduce tidal effects and improves the accuracy of land and water classification as well as shoreline determination.

Table 1: Landsat satellite images used in the study.

Acquisition	Path/Row	Satellite	Resolution	Number of bands
February 3, 1998	124/053	Landsat 5 (TM)	30m	7
January 25, 1998	125/053	Landsat 5 (TM)	30m	7
January 16, 2009	124/053	Landsat 5 (TM)	30m	7
January 7, 2009	125/053	Landsat 5 (TM)	30m	7
February 13, 2019	124/053	Landsat 8 (OLI & TIRS)	30m	11
January 19, 2019	125/052	Landsat 8 (OLI & TIRS)	30m	11
January 19, 2019	125/053	Landsat 8 (OLI & TIRS)	30m	11

Field data is an essential part of evaluating the results of the study. The field survey was conducted on February 20, 2019 (near the time of collecting Landsat satellite image data in 2019). In this study, we surveyed three locations, including one accretion location on Dong Tranh River (flowing through Long Hoa Commune) (Figure 2) and two erosion locations on Thanh An Island (in Thanh An Commune) (Figure 3) and Can Gio Beach (in Can Thanh Town) (Figure 4). At the time of the survey, the two erosion locations above were built with stone embankments and groynes to protect the shoreline.

Figure 2.: Accretion phenomenon in Dong Tranh River.

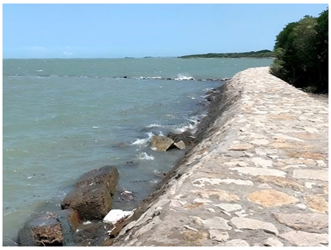

Figure 3: Stone embankment at Thanh An Island.

Figure 4: Stone groyne embankment at Can Gio Beach.

3.2 Shoreline determination

As presented in the previous section, there are many methods used in land and water classification to determine shorelines. However, in general, MNDWI has demonstrated its advantages over other methods in many applications related to water separation with other objects (Duru, 2017; Zhai, 2015). Therefore, in this study, we choose to use the MNDWI for land and water classification to determine shorelines. MNDWI is calculated according to Equation (1).

$$MNDWI = \frac{GREEN - SWIR}{GREEN + SWIR} \quad (1)$$

In which GREEN is the spectral band in the green wavelength region (0,52-0,60 μm), SWIR is the spectral band in the shortwave infrared region (1,55-1,75 μm). MNDWI values range from -1 to +1, in which negative values represent areas without water and positive values represent water areas. In this study, the threshold for classifying water and land areas is determined to be 0,2. This is the most appropriate threshold and yields the best classification results for the study area. Shorelines obtained at the satellite image times of 1998, 2009 and 2019, after being determined by MNDWI, will be overlaid to identify areas of accretion and erosion and calculate the area of variation.

3.3 Shoreline variation rate

To calculate the shoreline variation rate, we use the DSAS module of ArcGIS software version 10.8. The Linear Regression Rate (LRR) and End Point Rate (EPR) statistical methods are used to calculate the shoreline variation rate in the DSAS module. Previous studies using the LRR and EPR methods to monitor the shoreline variation rate of the study areas have shown that using the LRR method gives better results when calculating multiple shorelines in different periods, while the EPR method is effective when calculating between two shorelines (Milligan et al., 2010; Milligan et al., 2011). Using both the LRR and ERP methods allows for more effective calculation of the shoreline variation rate for the entire period 1998-2019, as well as the periods 1998-2009 and 2009-2019. At the same time, the above two methods are chosen in this study because they require the least input data compared to other statistical methods in the DSAS module.

The EPR is calculated by dividing the Net Shoreline Movement (NSM) by the time elapsed between the oldest and the most recent shoreline (Figure 5a). The significant advantages of the EPR are the ease of computation and the minimal requirement of only two shorelines. The disadvantage is that in cases where more data are available, the additional information is ignored (Himmelstoss et al., 2018). EPR is used to analyze results for the periods 1998-2009 and 2009-2019.

The LRR method was determined by plotting the shoreline intersections (distance from the baseline) regarding time (years) and calculating the linear regression equation y = ax + b (Figure 5b). The slope of the equation describing the line is the rate of shoreline variation (m/year). LRR is used to analyze the results for the period 1998-2019.

This study uses the DSAS version 5.0 module to calculate the accretion and erosion rates based on baselines, shorelines and transects (Figure 6). The study area has alternating accretion and erosion processes, so the baseline is determined towards the sea, 10 m from the nearest shoreline, while the shorelines included in the calculation are the shorelines of 1998, 2009 and 2019, respectively. The transects are 50 m apart and intersect each shoreline at one point. These intersection points are the basis for DSAS to perform statistical calculations. The classification of shoreline variation rates is shown in Table 2.

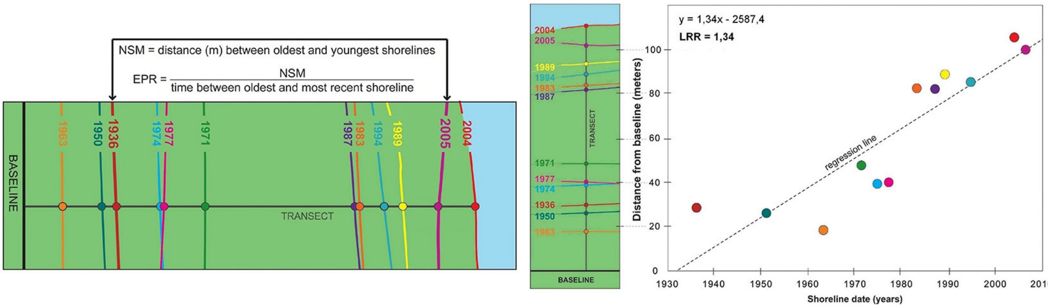

Figure 5: Method to calculate the shoreline variation rate: (a) EPR (b) LRR (Himmelstoss et al., 2018).

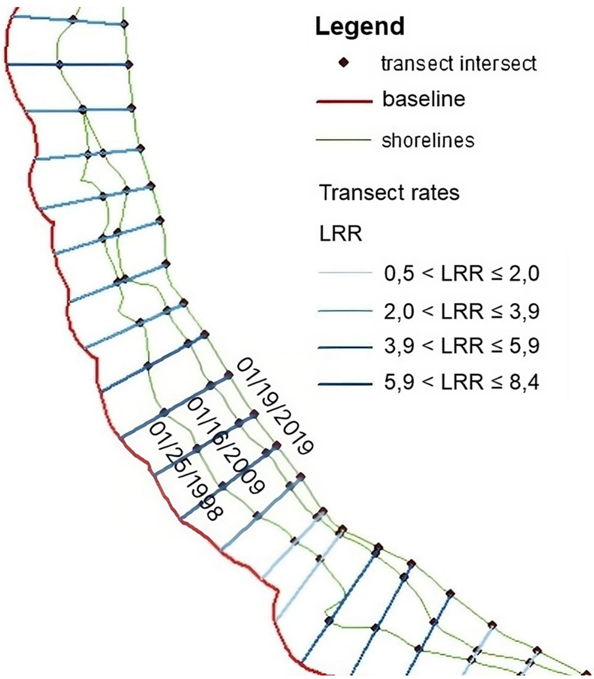

Figure 6: Baseline, shoreline and transect positions in the study.

Table 2: Classification of shoreline variation rate (Hong, 1996).

Evaluation criteria	Level	Variation Rate
Accretion or erosion rate	Slow	< 5 m/year
	Medium	5-10 m/year
	Fast	10-30 m/year
	Very fast	> 30 m/year

4 Results and discussion

4.1 Shoreline variation from satellite images period 1998-2019

The statistical results of the area of variation in the Can Gio District (Figure 7 & Table 3) show that the shorelines in the Can Gio District have intertwined erosion and accretion. The eroded shorelines are mostly straight shorelines, such as the Southern shore of Thanh An Island (Figure 7g); protruding headlands such as Ly Nhon Cape (Figure 7c), Can Gio Beach (Figure 7e); Nang Hai mangrove forest area (Figure 7d) and the riverbank along Long Tau River extending to Nga Bay River (Figure 7a & 7f). Straight shorelines and protruding headlands are terrain types that are regularly affected by waves, so erosion occurs continuously with strong intensity (Hai & Tuyen, 2011). Meanwhile, the area with accretion variation is the Dong Tranh River area extending to the river mouth (Figure 7b). If considered in the whole region, erosion is dominant, with the erosion area in all stages consistently higher than the accretion area, especially in the period 1998-2009, the erosion area was 2,1 times higher than the accretion area, while the erosion area of the total period 1998-2019 was 1,8 times higher than the accretion area. In just 21 years (1998-2019), the Can Gio District lost 500 ha of land, of which the average accretion area was 31,3 ha/year, and the average erosion area was 55,2 ha/year

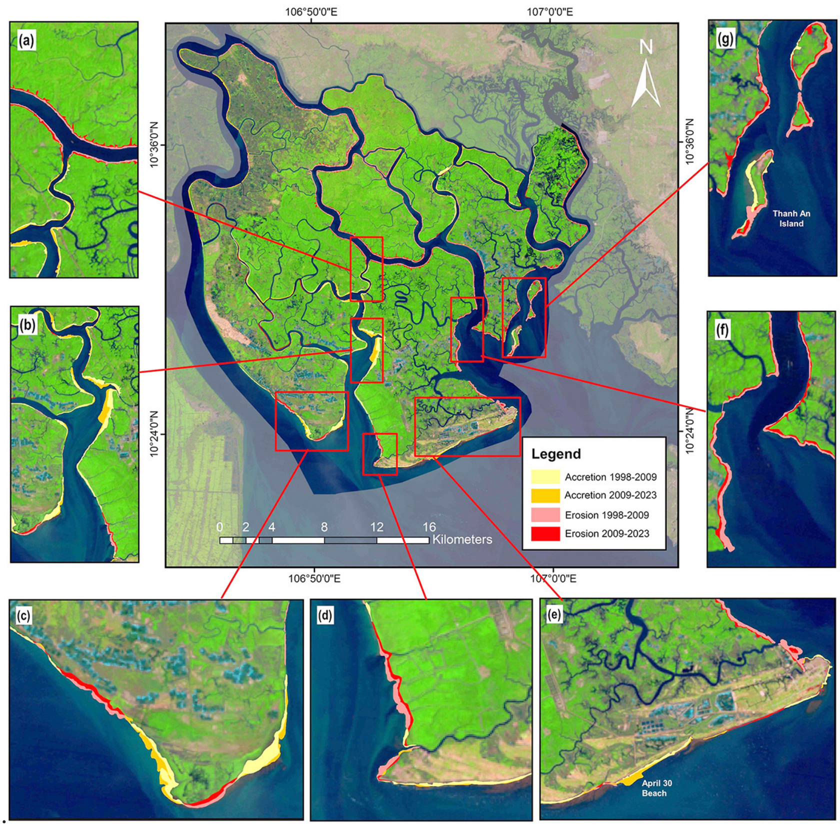

Figure 7: Erosion and accretion map of Can Gio District in 1998-2019: (a) Long Tau River (b) Dong Tranh River (c) Ly Nhon Cape (d) Nang Hai Mangroves (e) Can Gio Beach (f) Nga Bay River (g) Thanh An Island.

Table 3: Evolution of shoreline erosion and accretion in Can Gio District (Unit: ha).

Commune or Town	1998-2009			2009-2019			1998-2019		
	Erosion **(A)**	Accretion **(B)**	**B-A**	Erosion **(A)**	Accretion **(B)**	**B-A**	Erosion **(A)**	Accretion **(B)**	**B-A**
Binh Khanh	73,1	0,4	-72,8	20,2	22,4	+2,1	93,4	22,8	-70,6
An Thoi Dong	56,9	30,4	-26,5	31,5	53,5	+22,1	88,4	83,9	-4,5
Ly Nhon	29,7	111,6	+81,8	52,4	77,2	+24,9	82,1	188,8	+106,7
Tam Thon Hiep	226,4	27,3	-199,1	88,5	26,7	-61,9	314,9	54,0	-260,9
Long Hoa	110,9	128,1	+17,2	71,6	105,6	+33,9	182,6	233,7	+51,1
Can Thanh	36,3	8,5	-27,8	22,7	2,2	-20,5	59,0	10,7	-48,3
Thanh An	195,3	34,4	-161,0	143,2	30,1	-113,1	338,5	64,5	-274,1
Total	**728,6**	**340,7**	**-388,2**	**430,1**	**317,7**	**-112,5**	**1158,9**	**658,4**	**-500,6**

Note: the (-) sign is the lost area, the (+) sign is the increased area

Statistical results for each commune in 21 years (1998-2019) (Table 3) show that the risk of land loss in Thanh An Commune and Tam Thon Hiep Commune is very high. The leading cause is erosion on the Long Tau River flowing through these two communes. Thanh An Commune has the largest total erosion area, accounting for 29,2% of the erosion area of the whole district (1998-2019), with an average erosion of 16 ha/year in this commune. Research results show that erosion is concentrated on the Southern bank of Thanh An Commune and Thanh An Island. In addition, erosion also occurs on the two Northern islands of Thanh An Island on the Eastern and Southern banks (Figure 7g). Unlike the current status of these two islands, the Eastern bank of Thanh An Island in the period 1998-2019 was not severely affected by erosion. The reason is that since 1995, the Can Gio District government has built stone embankment systems on the East bank to limit the impact of sea waves (Figure 3). However, in the South, due to the lack of attention to building stone embankment systems, landslides still occur seriously. Tam Thon Hiep Commune is the commune with the second largest erosion area, with the total erosion area in the period 1998-2019 accounting for 27,2% of the total erosion area of the district, with an average land loss of 15 ha/year. Different from the erosion trend of Thanh An, Tam Thon Hiep and Binh Khanh communes, Ly Nhon and Long Hoa Communes tend to have more land accretion. The accretion area in these two communes increases mainly due to the alluvial plain in Dong Tranh River (the alluvial plain on the left bank belongs to Ly Nhon Commune, and the alluvial plain on the right bank belongs to Long Hoa Commune). The results are similar to the field survey conducted in 2019 (Figure 2), in which the accretion phenomenon occurred intensely in these areas. On average, the Ly Nhon Commune is accreted with 5,8 ha/year, while the Long Hoa Commune is accreted with 2,4 ha/year.

The main variation in the Can Gio Beach area (belonging to Long Hoa Commune and Can Thanh Town) is erosion. However, erosion in this area is not too severe due to the stone embankments that have protected the coast since 1994 (Figure 4). Therefore, the area of land lost in this area is not much. Erosion in Can Thanh Town is mainly concentrated on the East bank, where there are no protective structures. However, erosion in Can Thanh Town is generally not too severe. A special phenomenon occurs in Can Gio Beach when the April 30 Beach area (in Long Hoa Commune) has accretion (Figure 7e), although the main phenomenon in this area is erosion. Nevertheless, this is not a natural accretion phenomenon but an artificial construction from the Can Gio Beach encroachment tourism project. This contributes to increasing the area of accreted land for Long Hoa Commune.

4.2 Shoreline variation rates in typical areas

Based on the statistical results in Table 3, it can be seen that the two forms of variation of accretion and erosion in the Can Gio District are represented by the Dong Tranh River and Long Tau River (extending to Nga Bay River), respectively. Therefore, to further analyze the rate and causes of variation, the study used the DSAS module to calculate the rate of variation at some typical areas on these two river sections according to the LRR method for the period 1998-2019 and the EPR method for each period 1998-2009 and 2009-2019.

The results of calculating the shoreline variation rate for the period 1998-2019 using the LRR method are presented in Table 4 and Figure 8. The Dong Tranh River area (Figure 8a) has a main tendency of accretion with an average accretion rate of the left bank up to 8,9 m/year, and the location with the most significant accretion is 29,2 m/year, forming alluvial flats hundreds of meters wide. The area has a wide, shallow riverbed, which is not directly affected by waves from the Northeast and Southwest winds (Hai & Tuyen, 2011). Additionally, alluvium from the Saigon and Dong Nai rivers, brought in during the flood season, forms large alluvial flats on both riverbanks. At the same time, the mangrove forests in this area, with the typical species of Avicennia marina having strong growth, have encroached on the river along the alluvial land, forming forest belts along the Dong Tranh River and the canals inside. These forest belts stabilize the riverbank and prevent erosion. In addition, the Dong Tranh River is not affected by waves of large-tonnage ships, creating favorable conditions for mangrove forests to quickly encroach on the river mouth (Hirose et al., 2004), contributing to increasing the speed and area of alluvial deposition in this area.

Although the main trend in the Dong Tranh River area is accretion, the Nang Hai mangrove forest area (left bank of the Dong Tranh River) (Figure 8b) has the main variation being erosion. This seems unreasonable because mangrove forests normally have the effect of retaining land and limiting erosion. However, this area is strongly affected by the river flow and tides. Furthermore, this area is also affected by the excavation of shrimp ponds. Before these shrimp ponds, the flow and tides were balanced in natural conditions. The digging of shrimp ponds significantly changes the natural flow system of the river. When the tide rises, water easily overflows into the shrimp ponds, increasing the amount of water flowing into the river and causing riverbank erosion. On the contrary, when the tide is low, water from shrimp ponds drains into the river quickly, reducing the amount of alluvium and making the riverbank weak and susceptible to erosion (Mazda et al., 2002). Research by Hirose et al. (2004) showed that after each high tide in this area, whirlpools created by strong ebb currents will appear. The velocity of the tidal current is up to more than 70 cm/s, making it strong enough to wash away sediments at the river bottom and also cause erosion in the area. In the study by Phuoc and Massel in 2006, the authors determined that the main cause of erosion in this area was due to the wave field. Therefore, although this is an area with mangrove forests, the erosion trend will continue in the future (Thanh & Phuoc, 2019).

In contrast to the alluvial variation in the Dong Tranh River, the Long Tau River area extending to the Nga Bay River has a main trend of erosion. Accordingly, erosion also occurs along the banks of the Long

Tau River on both the left and right banks, extending to the river mouth of the Nga Bay River (Figure 8c & 8e). Specifically, during the period of 1998-2019, the average erosion rate of the Long Tau River area was about 2,9 m/year and 3,4 m/year for the Nga Bay River area. The reason is that this is a key waterway with large-capacity ships operating, bringing import and export goods to HCMC. The large area of alluvial deposits on the Dong Tranh River creates alluvial flats that narrow the riverbed and make waterway traffic difficult, so the circulation of waterways into HCMC is often carried out on the Long Tau River, where the riverbed is wide and deep (Hai & Tuyen, 2011). This area allows large-tonnage ships, with a capacity of 30.000-70.000 DWT, to transport import and export goods to HCMC via the route from Ganh Rai Bay to Nga Bay River and continue moving on the Soai Rap River. Moreover, this area also allows high-speed ships on the HCMC-Vung Tau route to operate, increasing wave height from 10-15 cm to over 1 m, hitting the shore directly (Thu et al., 2018). Without resistant mangrove belts, the erosion rate will be stronger. In addition, due to having mangrove forests, unwanted accretion can be prevented because eroded sediment from this area will follow the flow to downstream areas, leading to accretion of the port areas (Tien et al., 2002).

The Ly Nhon Cape area is the intersection of the Soai Rap and Dong Tranh River mouths. This is a special area where the accretion and erosion phenomena are intertwined (Figure 8d). The erosion in Ly Nhon is mainly concentrated in the cape area (where it is directly affected by waves and has no protective structures) and the Eastern bank towards the Soai Rap River, an area with a high population density, which has lost its vegetation cover to hold the shore, making the shoreline susceptible to erosion. At the same time, this is an area with strong variation, with the most considerable accretion reaching 18,8 m/year and the most considerable erosion in this area being 8,9 m/year. Therefore, the results of calculating the average fluctuation rate are suitable for areas with only one type of typical shoreline fluctuation (accretion or erosion) but not suitable for representing the fluctuation in areas with both accretion and erosion factors, such as Ly Nhon Cape.

Table 4: Shoreline variation rate (m/year) according to the LRR method in typical areas in Can Gio District during the period 1998-2019.

Location	Number of transects	Shoreline length (km)	Max variation (m/year)	Average (m/year)
Right bank of Dong Tranh River*	160	8	+8,6	+2,8
Left Bank of Dong Tranh River	270	7,4	+29,2	+8,9
Ly Nhon Cape	347	17,4	+18,8	+1,8**
Long Tau River	976	48,8***	-11,3	-2,9
Nga Bay River	647	32,4***	-18,2	-3,4
Nang Hai Mangroves	51	2,6	-11,4	-5,5

Note: The (-) sign represents erosion variation, the (+) sign represents accretion variation.

*: Determining the left and right banks of the river is based on the direction of the river flow.

**: The Ly Nhon Cape has alternating erosion-accretion phenomena, so it does not reflect the level of variation.

***: Including both the left and right banks of the river.

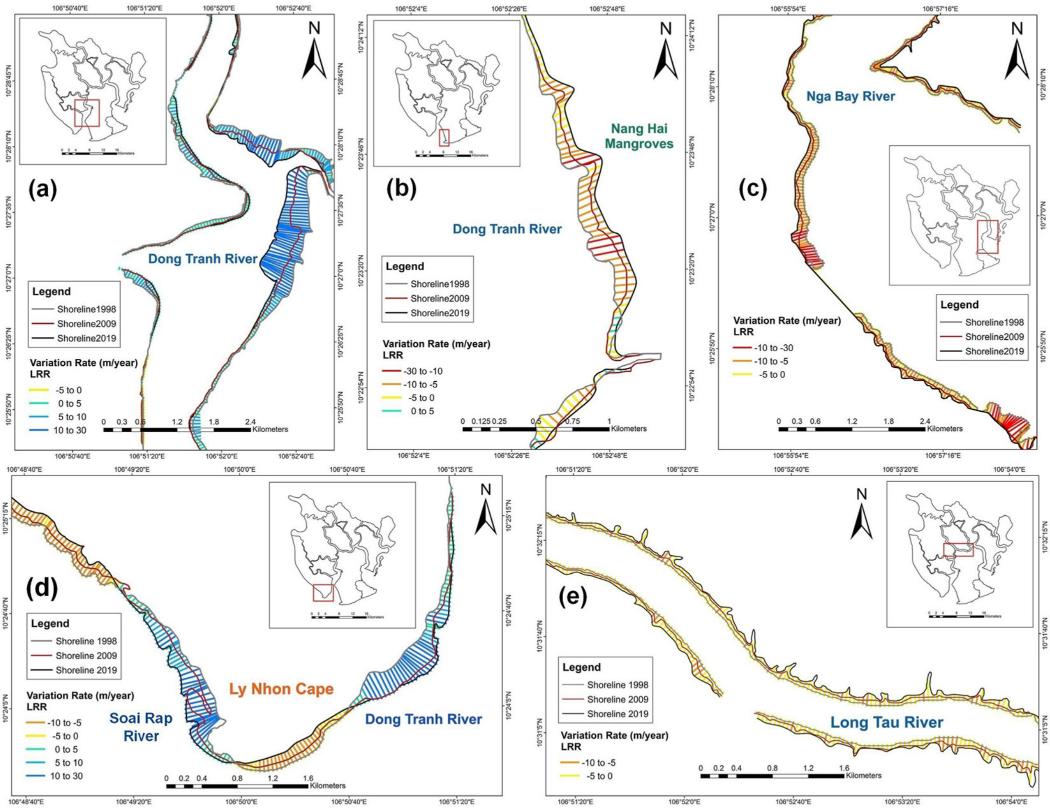

Figure 8: Shoreline variation rate according to the LRR method in (a) Dong Tranh River, (b) Nang Hai Magroves, (c) Nga Bay River, (d) Ly Nhon Cape, and (e) Long Tau River.

The results of calculating the shoreline variation rate for the periods 1998-2009 and 2009-2019 using the EPR method show that the accretion and erosion rate in 2009-2019 in the areas tended to decrease compared to 1998-2009. Distinct, the erosion rate in the Nang Hai mangrove forest area increased from 4,9 m/year (1998-2009) to 5,9 m/year (2009-2019). The rate of variation in the Dong Tranh and Long Tau River areas did not change much compared to the previous period, while the Ly Nhon Cape area still had accretion-erosion phenomena intertwined with an increasing erosion trend.

In the Nga Bay River area, the erosion rate was calculated using the EPR method, showing that in 1998-2009, the erosion rate was 4,4 m/year and decreased to 2,7 m/year in 2009-2019. In 2014, the dredging of Soai Rap River made the river capable of receiving ships with a capacity of up to 50,000 DWT, contributing to reducing the load on the Nga Bay River. Therefore, the activities of ships on the Nga Bay estuary also decreased significantly. However, the dredging and clearing of the Soai Rap River is likely to affect the flow velocity and water flow through both the Soai Rap and Long Tau Rivers, leading to erosion at the Soai Rap riverbank due to deep dredging of the riverbed and the risk of accretion at Long Tau due to reduced flow velocity.

Table 5: Shoreline variation rate (m/year) according to EPR method in typical areas in Can Gio District for each period 1998-2009 and 2009-2019.

Location		Number of transects variation rate (m/year)							Average (m/year)
		-30 to -10	-10 to -5	-5 to 0	0 to 5	5 to 10	10 to 30	Total	
Right bank of Dong Tranh River	1998-2009	0	0	5	117	35	3	160	+3,1
	2009-2019	0	0	20	105	21	12	158	+2,8
Left Bank of Dong Tranh River	1998-2009	0	0	0	118	60	90	268	+8,1
	2009-2019	0	0	3	168	22	54	247	+7,2
Ly Nhon Cape	1998-2009	1	43	66	154	32	42	338	+3,1
	2009-2019	15	47	59	140	33	30	324	+1,2
Long Tau River	1998-2009	13	164	841	5	0	0	1023	-3,6
	2009-2019	61	139	623	179	3	2	1007	-3,5
Nga Bay River	1998-2009	46	161	453	73	0	0	733	-4,4
	2009-2019	13	67	474	54	4	0	612	-2,7
Nang Hai Mangroves	1998-2009	4	28	9	7	3	0	51	-4,9
	2009-2019	4	27	20	0	0	0	51	-5,9

Note: The (-) sign represents erosion variation, the (+) sign represents accretion variation

4.3 Proposed solutions to prevent and minimize the harmful effects of shoreline variation

Shoreline variations in the Can Gio District occur due to many causes, so proposing mitigation solutions also requires a synchronous combination of solutions together and cannot be solved separately. Strengthening inspection and timely response to landslide-accretion risks is a task that must be prioritised to protect people's lives and property and promptly respond to erosion and accretion. Classifying areas with high erosion risks and hotspots is necessary to conduct inspection and monitoring work in these areas regularly. At the same time, facing the impact of climate change accompanied by disasters such as rising sea levels, storms, floods, etc., the authorities need to prepare the worst scenarios to relocate or evacuate people promptly, avoiding landslide disasters that affect people's lives and property, especially people in riverside areas and Thanh An Island area.

At the same time, it is necessary to strengthen management by legal tools to limit the negative impacts of sand mining activities in the Can Gio District, which is one of the causes of erosion in the area. The authorities need to have regulations to strictly manage this activity, especially when the Can Gio Beach encroachment project is about to start construction; illegal sand mining will be a concern for the area. Accordingly, the authorities must clearly define which areas and river sections are allowed to mine sand and which are prohibited. In parallel, there should be patrol teams and strict sanctions if violations of the above regulations are caught. Tightening policies and projects to suit reality is crucial to reducing illegal sand mining that affects shoreline erosion.

The Can Gio District has a large area of mangrove forests along with an intricate system of canals, so on-site monitoring and field measurements still face many difficulties. Therefore, it is necessary to apply additional scientific measures, such as geospatial technologies for remote monitoring and modelling, to forecast variations in order to detect areas at risk of erosion and accretion promptly. At the same time, periodic monitoring of erosion and accretion should be based on coordination between central scientific agencies and local technical units to provide appropriate solutions for each locality. Establish erosion and accretion hazard maps for the Can Gio District, including details of hotspot points for managers as reference materials. Especially during the period of implementing the construction of the Can Gio coastal urban area project, it is necessary to conduct more scientific research to assess and forecast the possible impacts that may affect this area.

In addition to management solutions, technical solutions for coastal protection also need to be focused on. The construction of embankment systems made of stacked stone or reinforced concrete is an urgent task to protect coastal areas at high risk of erosion. In addition, one of the regional solutions is to preserve and develop the mangrove ecosystem. Mangrove forests play an essential role in retaining land and minimizing erosion caused by the effects of waves and tides. For areas affected by accretion, dredging and clearing the flow are proposed technical solutions. However, caution and careful calculation are also needed because, as presented above, clearing the flow of one river branch can limit the flow of another river branch, thereby causing accretion.

5 Conclusion

With the pace and scale of investment in the socio-economic development of the coastal strip increasing rapidly, it is necessary to ensure sustainable development. Shoreline protection and prevention of erosion and accretion have become urgent requirements. The paper uses remote sensing images from Landsat-5 and Landsat-8 satellites with a spatial resolution of 30 m collected during the dry seasons of 1998, 2009 and 2019, combined with the use of MNDWI and the DSAS module, showing that the Can Gio area has intertwined erosion and accretion. Erosion is mainly concentrated in the Long Tau River area extending to the Nga Bay River, while accretion tends to be concentrated in the Dong Tranh River area. The phenomenon of shoreline variation generally tends to decrease in the later period (2009-2019) compared to the previous period (1998-2009) due to the effects of embankment protection works, efforts to restore mangrove forests and the application of management measures. Thus, by exploiting information from geospatial technologies, the study has shown a general picture of the variation in riverbanks and coastlines in the Can Gio District from the past to the present (1998-2019). With a large coverage of remote sensing images, the information on riverbank and coastline variation captured is uniform. The information exploited from remote sensing images is not only about variation in riverbanks and coastlines but also about related objects such as information on embankments, dikes, dams, ground cover, etc. Based on this information, it is possible to assess the causes of coastal erosion and evaluate the effectiveness of prevent erosion solutions. It can be said that geospatial technologies can provide an overall picture of coastal erosion not only in the Can Gio area but also nationwide. Therefore, in the current situation of increasingly severe shoreline erosion, geospatial technologies in erosion monitoring need to be focused on and applied. The results from the article are consistent with previous studies and field data and can be used to provide information to serve the management, monitoring and protection of coastal ecosystems as well as to establish maps of shoreline evolution.

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