UDC 556.537(597)
DOI: 10.18799/24131830/2025/4/4677

Shoreline fluctuation of Dong Tranh Estuary, Can Gio District, Ho Chi Minh City in the background of the climate variability

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Abstract. ***Relevance.*** Mangrove forests, especially thriving in the Mekong Delta and Ca Mau, play an important role in the ecosystem of southern Vietnam. A typical example is Can Gio mangrove forest in Ho Chi Minh City with an area of 35000 hectares, known as the "green lung" of the city. However, recently, the effects of climate change have made erosion worse due to changes in hydrodynamics and extreme weather events, leading to the shrinking forest areas. This affects not only the tourism industry but also aquaculture activities in the area. ***Aim.*** This study focuses on providing updated information on erosion and deposition at Dong Tranh Estuary, Can Gio District. Through this analysis, management agencies will have more basis to propose effective measures to protect and develop this area, especially in the increasingly complex climate change situation. ***Methods.*** Shoreline extraction method in combination with GIS to calculate the coastline change and combines with field surveys to check and analyze results, helping to clarify the causes of erosion and deposition. ***Results.*** Within the framework of the study, areas 2 and 3 were identified as places strongly affected by waves and tides, with serious erosion levels, especially in the Nang Hai area with erosion rates reaching –3.9 m/year. In contrast, area 1, mainly affected by Dong Tranh Estuary, recorded a significant deposition rate, reaching 7.05 m/year. The results of this study are valuable as an important reference source, supporting the management and consolidation of coastlines, and proposing effective protection measures to limit erosion.

Keywords: shoreline extraction, GIS, erosion, deposition, Can Gio, Dong Tranh Estuary, NDVI

Acknowledgements: This research is funded by University of Science, VNU-HCM under grant number T2024-11.

For citation: Nguyen Tien Thanh. Shoreline fluctuation of Dong Tranh Estuary, Can Gio District, Ho Chi Minh City in the background of the climate variability. *Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering*, 2025, vol. 336, no. 4, pp. 7–15. DOI: 10.18799/24131830/2025/4/4677

УДК 556.537(597)
DOI: 10.18799/24131830/2025/4/4677

Колебания береговой линии реки Донг Чан, Район Кан Гио, Хошимин, на фоне изменчивости климата

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Аннотация. ***Актуальность.*** Мангровые леса, особенно процветающие в дельте Меконга и Камау, играют важную роль в экосистеме южного Вьетнама. Типичным примером является мангровый лес Кан Гио в Хошимине площадью 35000 гектаров, известный как «зеленые легкие» города. Однако в последнее время последствия изменения климата усугубили эрозию из-за изменений в гидродинамике и экстремальных погодных явлений, что привело к сокращению лесных площадей. Это влияет не только на индустрию туризма, но и на деятельность в области аквакультуры в этом районе. ***Цель.*** Настоящее исследование направлено на предоставление обновленной информации об эрозии и отложениях в устье реки Донг Трань в районе Кан Гио. Благодаря этому анализу у органов управления будет больше оснований предлагать эффективные меры по защите и развитию этой области, особенно во все более сложной ситуации с изменением климата. ***Методы.*** Метод извлечения береговой линии в сочетании с ГИС для расчета изменения береговой линии и в сочетании с полевыми исследованиями для проверки и анализа результатов для уточнения причин эрозии и седиментации. ***Результаты.*** В рамках исследования районы 2 и 3 были определены как места, сильно подверженные воздействию волн и приливов, с серьезным уровнем эрозии, особенно в районе Нангхай, где скорость эрозии достигает –3,9 м/год. Напротив, в районе 1, находящемся главным образом под влиянием реки Донг Чан, была зафиксирована значительная скорость седиментации, достигающая 7,05 м/год. Результаты этого исследования – важный справочный источник, поддерживающий управление береговыми линиями и их консолидацию, а также предлагающий эффективные меры защиты для ограничения эрозии.

Ключевые слова: извлечение береговой линии, ГИС, эрозия, отложения, Кан Гио, устье Донг Чан, NDVI

Благодарности: исследования выполнено при финансовой поддержке Университета науки, Вьетнам, грант № T2024-11.

Для цитирования: Нгуен Тьен Тхань. Колебания береговой линии реки Донг Чан, Район Кан Гио, Хошимин, на фоне изменчивости климата // Известия Томского политехнического университета. Инжиниринг георесурсов. – 2025. – Т. 326. – № 4. – С. 7–15. DOI: 10.18799/24131830/2025/4/4677

Introduction

Forests are considered as the "green lung" of the earth, they play a very important role in maintaining ecological balance and biodiversity on the planet. Therefore, protecting forests and forest resources has always become a task that cannot be postponed for all countries in the world, including Vietnam [1]. Vietnam has 29 provinces and cities with forests and coastal mangrove lands stretching from Mong Cai to Ha Tien. Mangrove forests have a large distribution area and thrive in the south, especially in the Ca Mau region – the Mekong Delta. In which, Can Gio mangrove forest with an area of 35000 hectares is considered as the "green lung" of Ho Chi Minh City. In addition, mangrove forests make an important contribution to preventing erosion caused by impacts from the sea such as storms, waves, currents, etc., creating shoreline stability for the area [2–4]. Under the impact of climate change in recent years, shoreline erosion has become more serious, causing the mangrove forest area to shrink and affecting not only the tourism industry but also aquaculture activities, seafood in the area [5]. Shoreline changes are not only the result of natural factors (river morphology, geological structures, currents, etc.), but also human interventions such as sand mining, navigation and build reservoir dams upstream [6]. Therefore, monitoring the evolution of shoreline changes in the Ho Chi Minh City area and predicting changing trends is necessary for the protection and sustainable management of the shoreline.

Around the world, many studies have used remote sensing data to classify water surfaces using multi-temporal satellite images, which are then overlaid to identify and evaluate shoreline changes.

Chettiyam Thodi et al. investigated the shoreline change at Vypin, Vallarpadam and Bolgatty islands using remote sensing images combined with GIS for the period from 1973 to 2019. The results show that that under the impact of human activities, these islands have been subjected to accretion on both sides of the coast, leading to the formation of new land areas. This is determined through the analysis of statistical indicators such as Net Shoreline Movement (NSM), End Point Rate (EPR), and Linear Regression Rate Calculate (Linear Regression Rate – LRR) in the Digital Shoreline Analysis System (DSAS) [7]. Mondal et al. studied the Ghoramara island area in the Hugli estuary, West Bengal in India from 1972 to 2022 using remote sensing images. The results show that the average, minimum, and maximum EPR are –10.59, –4.13, and –35.93, with greatest erosion in the north, southeast, and west regions [8]. Muhammad Yasir et al. used Landsat images and GIS technology to calculate shoreline changes in the Qingdao coastal area from 2000 to 2019. Using the parameters of NSM, EPR, and LRR in DSAS to analyze shoreline changes in the study area shows that the maximum deposition and maximum erosion achieved corresponding to the above three parameters are 266.07, 2391.85, 124.47 m/yr, and –142.55, –1234.59, –63.22 m/yr [9]. Ke Mu at el. has adjusted the position of the eastern coastline of Lai Chau Bay, China, using the Otsu algorithm and adjusted the tides in the period from 1984 to 2022 from remote sensing images of Landsat 5 (TM), Landsat 8 (OLI) and Sentinel-2 (MSI). They show that based on EPR and LRR methods more than 70% of sandy beaches are eroded for 79.54 and 85.58% [10].

Besides, there have been many studies on shoreline changes conducted in Vietnam in recent years. Phan Vo Tieu Phuong et al. calculated shoreline changes in the Tien Giang to Soc Trang area using remote sensing images combined with GIS, showing that in 2021–2023, the coastline length eroded by 63.71% and decreased to 59.03% for 2022–2023. In addition, we can see slight erosion in Tien Giang, Ben Tre and Soc Trang areas, while erosion increases rapidly in Tra Vinh area for 2021–2023 [11]. Le Van Tuan et al. applied Alesheikh's method on Landsat image data from 1990 to 2020 to study the level of riverbank fluctuations at Phu Da island. They used the Digital Shoreline Analysis System (DSAS), an extension of

GIS, to calculate the extent of erosion and deposition during this time. The results show that this process occurs alternately, with erosion dominating. During the 30-year period from 1990 to 2020, the erosion area in Phu Da island area reached about 125.46 hectares. The smallest erosion range is 10 m, appearing on both sides and tail of the dune. The largest riverbank fluctuation measured is 723.83 m at the southern tip of the dune. This fluctuation, in which erosion predominates, plays an important role in the serious landslide phenomenon that has occurred in recent times [12]. Vuong Trong Kha et al. used Sentinel-2A satellite images taken on December 1, 2015 and March 9, 2020 to determine the water-land boundary on the basis of the automatic water separation index (AWEI), which is overlaid to detect river bank line changes. The results showed that, in the period from 2015 to 2020, the Chu River shoreline had very complex fluctuations, which recorded both erosion and deposition. The largest erosion rate is up to 37 m/yr in the center of the study area, where sand and gravel dredgers are concentrated [13].

Research area and methods

Research area

Can Gio district is located between East longitude from 106°46'12" to 107°00'50" and North latitude from 10°22'14" to 10°40'00". This area is famous for large estuaries such as Long Tau, Cai Mep, Go Gia, Thi Vai, Soai Rap, and Dong Tranh (Fig. 1). Can Gio has a sub-equatorial tropical monsoon climate, divided into two distinct seasons: the rainy season lasts from June to October and the dry season from November to May of the following year. In this area, average temperatures range from 25 to 29°C, and average humidity ranges from 73 to 85%. The average annual rainfall ranges from 1,300 to 1,400 mm, with the highest monthly rainfall (300–400 mm) in September. The prevailing wind direction during the rainy season is southwest, with the strongest wind speeds occurring in July and August. In the dry season, the dominant wind direction shifts to northeast, with strong winds in February and March [14].

Data and methods

Data

Landsat 8 images were collected from the website of the US Geological Survey with a resolution of 30 m, less affected by clouds and very good image quality (Table 1). The study also used high-resolution Google Earth images to process and compare shoreline extraction results. In addition, this study conducted a shoreline survey in the Nang Hai area of Dong Tranh Estuary, Can Gio, Ho Chi Minh City to compare and contrast trends with the results of shoreline extraction.

The actual shoreline data series was measured with a GPS device (GPS map 76CSx) over the years 2013, 2015, 2017, 2024. Proceed along the edge of the forest for more than 200 m. The shoreline convention here is the boundary between the forest and the mudflats.

Shoreline data were collected in four surveys by the Departments of Oceanology, Meteorology and Hydrology.

1) Phase 1 on April 20, 2013
2) Phase 2 on February 4, 2015
3) Phase 3 on May 25, 2017
4) Phase 4 on March 24, 2024

Then, Mapsource software was used to retrieve the shoreline data from the GPS locator. Then the shoreline data were processed, eliminating unnecessary data (disturbed, overlapping and inconsistent with the actual shoreline). After processing, the shoreline data were imported into ArcGIS 10.5 software to calculate shoreline changes using the DSAS tool. Garmin GPS Map 76CSx handheld navigation device.

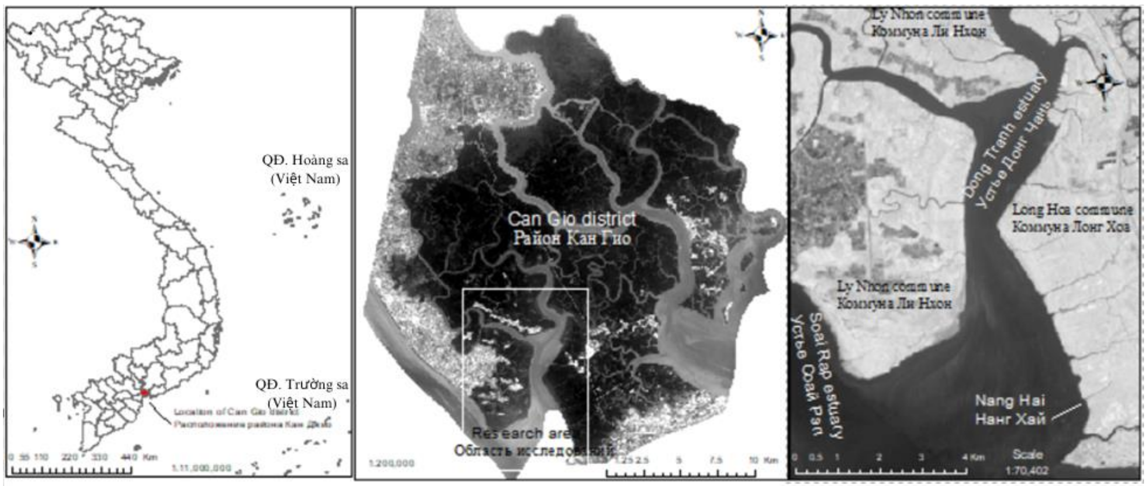

Fig. 1. *Location of Can Gio District and research area*

Рис. 1. *Расположение района Кангио и территории исследования*

Table 1. *Collecting remote sensing images*

Таблица 1. *Сбор изображений дистанционного зондирования*

Area Область	Collecting satellite images Сбор спутниковых снимков	Spatial resolution, m Пространственное разрешение, м	Landsat images Изображения Landsat
Can Gio Кан Джио	26/10/2013	30	LC08
	18/02/2015		
	06/01/2017		
	17/03/2019		
	22/03/2021		
	22/03/2024		

Methods

The ENVI 5.1 tool is used in the research to process remote sensing images through the following steps:

1. *Geometric correction*: to correct errors that arise during image capture and standardize image coordinates to match other data sources, geometric correction is performed. The process is based on carefully selected geographical control points on the ground, such as forks and intersections of streets, or where rivers and streams meet. These points are evenly distributed throughout the area that needs correction to ensure the effectiveness of this process [15].
2. *Digital conversion to spectral reflectance value*: for reducing the discrepancy in spectral reflectance values of objects across various sensor types and images.
3. *Calculation of NDVI* (Normalized difference vegetation index) (Fig. 2).
   For Landsat 8 OLI/TIRS images:

$$NDVI = \frac{B_5 - B_4}{B_5 + B_4}.$$

In which, B5 is the near-infrared (NIR) channel and B4 is the red light channel (Red) [16].

The main goal of this step is to enhance the display of plant objects on the ground, in order to evaluate their development status. This is done through the NDVI index, which reflects the chlorophyll content in plants. A high NDVI index indicates that the vegetation in that area is growing well, while a low NDVI index indicates that the area has no vegetation or that the vegetation is growing poorly [17]. Then, the shoreline analysis results of each time period are placed on the corresponding Google Earth map to check and confirm the accuracy of the classification.

The research team conducted four field surveys in April 2013, February 2015, May 2017 and March 2024 in the Nang Hai area. During these surveys, the team collected important data such as the location of the shoreline, erosion sites, and encroached areas for clam flat farming. The results of this survey are intended to test and validate analyzes of shoreline fluctuations and help explain the causes of these fluctuations.

4. *Shoreline change analysis by applying DSAS*: to be able to assess shoreline changes quantitatively, we need to use the DSAS tool to help users calculate the extent of shoreline changes over time based on the complex position of the shoreline (Fig. 2) [18–20].

In DSAS, there are many statistical methods for calculating shoreline changes such as Net Shoreline Movement (NSM), EPR, LRR. The EPR method is considered as one of the best one to assess shoreline change because it is easy to calculate and it requires minimal shoreline data [21]. EPR value is calculated according to the formula:

$$EPR = \frac{\text{Distance between oldest and newest shorelines}}{\text{Time−lapse between shorelines}} \text{ (m/yr).}$$

The calculation and analysis of the shoreline is carried out as follows:

- determination of baseline and shorelines;
- creation of horizontal secant lines perpendicular to the shore (transect);
- calculation of the shoreline change rate.

In this study, to determine the EPR value, I set the Baseline as the line outside the Dong Tranh Estuary, creating transects evenly spaced 20 m apart, a total of 1431 transects.

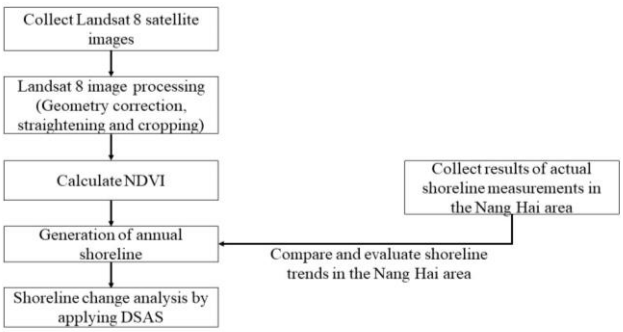

Fig. 2. *Flowchart of the overall methodology adopted to conduct this study*

Рис. 2. *Блок-схема общей методологии, принятой для проведения данного исследования*

Results and discussion

This study focuses on assessing shoreline changes in the Dong Tranh Estuary area, Can Gio, Ho Chi Minh City. The research area is divided into two main parts: area 1 is mainly affected by the Dong Tranh Estuary and is less affected by ocean waves; areas 2 and 3 are places directly affected by ocean waves (Fig. 3).

Analysis results show that during the period from 2013 to 2024 (Fig. 3), the shoreline of Dong Tranh Estuary area will have alternating erosion and deposition. The deposition mainly occurs in areas influenced by Dong Tranh Estuary and is less affected by ocean waves, while the erosion is concentrated in areas strongly affected by ocean waves

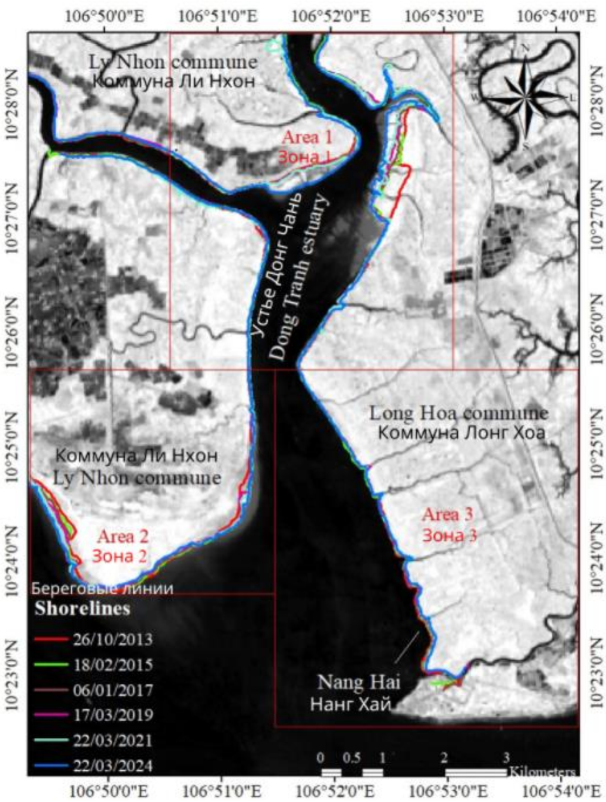

Fig. 3. *Shoreline changes in Dong Tranh Estuary, Can Gio District from 2013 to 2024*

Рис. 3. *Изменения береговой линии в устьевых районах Донг Чан и Кан Гио в 2013–2024 гг.*

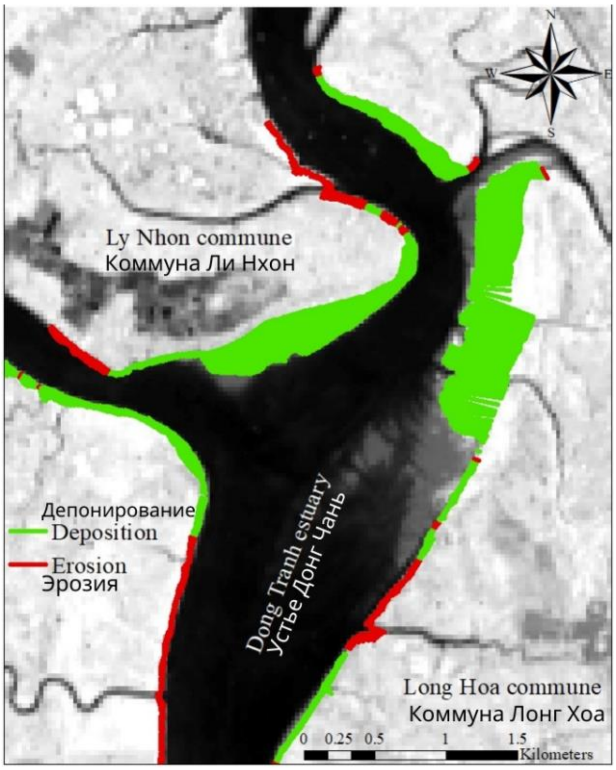

Fig. 4. *Shoreline changes in area 1*

Рис. 4. *Изменения береговой линии на участке 1*

Area 1 has a total of 770 transects, of which erosional transects are 231 and 30%, accretionary transects are 536 and 69.6% (Table 2). This area is mainly affected by the Dong Tranh Estuary, which tends to accumulate about 7.05 m/yr, forming mudflats hundreds of meters wide (Fig. 4). The cause of this phenomenon is due to the silt source from the Saigon and Dong Nai rivers during the flood season and the amount of sand and mud brought in during the southwest monsoon season. In addition, this area is not directly affected by waves created by Northeast and Southwest winds. The deposition phenomenon in Dong Tranh Estuary has made waterway transportation very difficult, only small boats can enter and exit, so mangrove forests are gradually encroaching on the river mouth, contributing to increasing the area of deposition capacitor for this area. This result is also quite consistent with previous studies. For example, Thu et al. calculated an accretion rate of about 4.75 m/yr [6], while Duong et al. estimated an accretion rate of about 35 and 29% in this area [22]. The erosion occurs relatively low in this area, only about –0.43 m/yr.

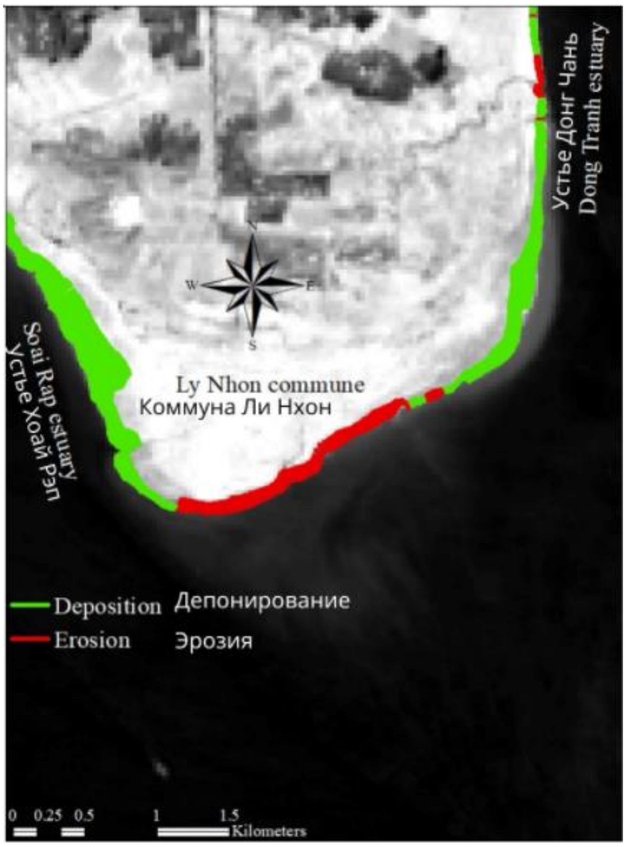

Fig. 5. *Shoreline changes in area 2*

Рис. 5. *Изменения береговой линии на участке 2*

Area 2 has a total of 391 transects, of which erosional transects are 124 and 31.7%, accretionary transects are 267 and 68.3% (Table 2). Area 2 belongs to the estuary of Soai Rap and Dong Tranh Estuary (Fig. 5), where the river bed is wide and shallow, the coast has a protruding nose and this area is directly affected by waves, so the coastline has many strong fluctuations, with alternating erosion and deposition phenomena [23]. Moreover, this area is concentrated with large shrimp ponds, the vegetation cover is lost, leading to reduced wave blocking ability [6]. In general, deposition is still more dominant than erosion, specifically deposition reaches 5.60 m/yr and erosion reaches –1.62 m/yr. The research results of Nam and his colleagues also show that erosion and deposition took place alternately for 1953–2010, with deposition being more dominant. Specifically, in the periods 1965–1973, 1989–1997 and 1997–2010, the accretion area was 136, 38.6 and 697 hectares respectively [24].

Area 3 has a total of 270 transects, of which erosion transects are 169 and 62.6%, accretion transects are 101 and 37.4% (Table 2). This area, like area 2, is directly affected by waves. In addition, this area has a straight coastline, a terrain type that is often affected by waves, so erosion occurs at high intensity, strength, especially in Nang Hai area (Fig. 6). Specifically, erosion reached –2.55 m/yr, deposition reached 0.31 m/yr, and in Nang Hai area, erosion reached –5.5 m/yr. GENESIS model results by Thanh et al. also shown that waves are the main cause of erosion in the Nang Hai area during the Northeast monsoon season [25]. According to the research by Yoshihiro Mazda et al., the erosion rate in Nang Hai is about 50 m/yr [26]. Calculation results of Hong Phuoc and Massel also confirmed that wave fields are the main cause of erosion in this area [27].

Actual survey results in the Nang Hai area show that the coastline is seriously eroded, especially the area near the creek (Fig. 7). Through the calculation results of 4 surveys of the Nang Hai coastline from April 20, 2013 to March 24, 2024, in general, the coastline only has erosion occurring at about –3.9 m/yr (Fig. 8). The survey results are consistent with the results of remote sensing image analysis. However, the actual survey erosion speed –3.9 m/yr is lower than the remote sensing image result –5.5 m/yr, possibly due to the resolution of the remote sensing image being 30 m lower than the remote sensing images resolution. GPS locator resolution is 3–15 m. In particular, in recent years, a lot of spontaneous oyster farming projects in the Nang Hai area have appeared (Fig. 9), which may be the cause of tidal and coastal current disturbances and the transmissions. These impacts can cause changes in erosion and deposition patterns, changes in turbidity, and local deposition. In addition, the Nang Hai area is also partly affected by ship waves passing through the oyster farming area.

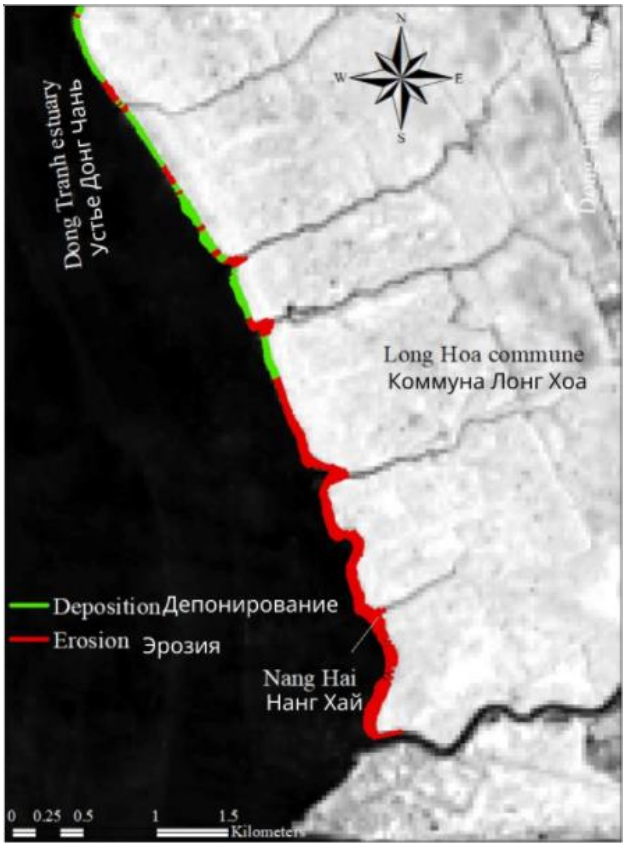

Fig. 6. *Shoreline changes in area 3*
Рис. 6. *Изменения береговой линии на участке 3*

Fig. 7. *Field survey of Nang Hai area March 24, 2024*
Рис. 7. *Полевые исследования района Нангхай, 24 марта 2024 г.*

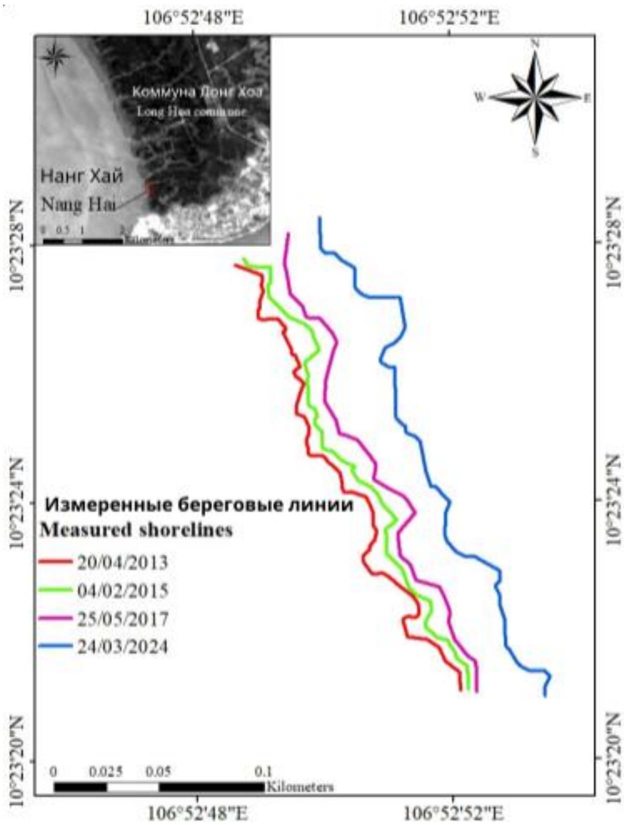

Fig. 8. *Measured shoreline changes from 2013 to 2024*
Рис. 8. *Измеренные изменения береговой линии с 2013 по 2024 гг.*

Conclusions

In this study, Landsat 8 remote sensing images were used to assess shoreline changes in the Dong Tranh Estuary area for 2013–2024. The results show that the shoreline is directly affected by waves and tides. As for Ly Nhon cape (area 2) and the southern area of Long Hoa (area 3), here erosion and deposition are concentrated mainly in the area affected by Dong Tranh Estuary (area 1).

The results of the shoreline survey in the Nang Hai area show that erosion has occurred at –3.9 m/yr. Under the effect of climate change and sea level rise in the near future, the erosion trend will continue in the future.

Overall, the results of this study can be used as a target reference for shoreline consolidation management and the introduction of limited protection measures. From there, it helps coastal authorities come up with appropriate strategic policies for economic development and shoreline protection.

Despite making the most of image sources and research methods, the quality of remote sensing images with limited spatial resolution can still affect the accuracy of research results. Therefore, it is necessary to use images with higher resolution to increase the accuracy of the results. In particular, more field survey points need to be carried out to compare and contrast with remote sensing data, ensuring the reliability and comprehensiveness of the research.

Table 2. *Descriptive statistics of the research area*
Таблица 2. *Описательная статистика области исследований*

Descriptive Statistics/Описательная статистика	Area 1/Зона 1	Area 2/Зона 2	Area 3/Зона 3	Total/Общий
Transect ID range Диапазон идентификаторов трансектов	271–1040	1041–1431	1–270	1–1431
Total number of transects/Общее количество трансектов	770	391	270	1431
Transects exhibiting erosion/Трансекты с эрозией	231	124	169	524
Transects exhibiting deposition Трансекты, демонстрирующие отложения	536	267	101	904
Stable transects/Стабильные трансекты	3	0	0	3
Percentage of transects exhibiting erosion (%) Процент трансектов с эрозией (%)	30	31.71	62.59	36.62
Percentage of transects exhibiting deposition (%) Процент трансектов, на которых наблюдаются отложения (%)	69.61	68.29	37.41	63.17
Percentage of stable transects Процент стабильных трансектов	0.39	0	0	0.21
Mean shoreline change (m/yr) Среднее изменение береговой линии (м/год)	6.62	3.98	–2.24	4.23
Maximum shoreline change (m/yr) Максимальное изменение береговой линии (м/год)	46.11	27.59	3.02	46.11
Minimum shoreline change (m/yr) Минимальное изменение береговой линии (м/год)	–13.39	–10.6	–15.23	–15.23
Mean erosion rate (m/yr) Средняя скорость эрозии (м/год)	–0.43	–1.62	–2.55	–1.16
Standard deviation for erosion rate (m/yr) Стандартное отклонение скорости эрозии (м/год)	1.13	2.82	2.98	2.29
Mean deposition rate (m/yr) Средняя скорость осаждения (м/год)	7.05	5.60	0.31	5.38
Standard deviation for deposition rate (m/yr) Стандартное отклонение скорости осаждения (м/год)	11.30	6.73	0.55	9.35

Fig. 9. *Oyster farming in Nang Hai area, March 24, 2024*
Рис. 9. *Разведение устриц в районе Нангхай, 24 марта 2024 г.*

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Received: 03.05.2024
Revised: 31.05.2024
Accepted: 31.01.2025

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Поступила в редакцию: 03.05.2024
Поступила после рецензирования: 31.05.2024
Принята к публикации: 31.01.2025