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Estimation of erosion-deposition trends across the Quang Nam coast in the background of the climate variability

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Abstract. ***Relevance.*** In the face of current climate change trends, coastal erosion occurs more frequently in coastal lands. This problem not only causes damage to houses and works, but also affects the lives of coastal people. Quang Nam has a coastline of 125 km, which is an area that has been seriously eroded under the impact of hydrodynamic factors, along with extreme weather phenomena, affecting people's lives, and degrade the local economy. ***Aim.*** This article presents research on shoreline changes in Quang Nam region using the method of integrating remote sensing and GIS to create a change map. From there, identify erosion and deposition areas to help management agencies pay attention to the protection and development orientation of Quang Nam province in the context of climate change. ***Methods.*** Shoreline extraction method in combination with GIS to calculate the coastline change and combines with storm statistics to assess the shoreline change. ***Results.*** In the whole study area, erosion is dominant over deposition. Erosion is concentrated mainly in An Bang, North Cua Dai, Duy Hai and Tam Tien areas, ranging from 3.9–9.2 m/year. Deposition is concentrated mainly in the areas south of Cua Dai and Tam Hoa (near the mouth of Truong Giang river). In addition, the analysis results of shoreline changes in Quang Nam area, when combined with storm data affecting this area, also show a positive correlation. Research results can contribute useful information to local authorities to have solutions for planning and managing coastal areas.

Keywords: shoreline extraction, GIS, erosion, deposition, Quang Nam, MNDWI

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Оценка тенденций эрозии и аккреции на побережье Куанг Нама на фоне изменчивости климата

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Аннотация. ***Актуальность.*** Перед лицом нынешних тенденций изменения климата береговая эрозия чаще происходит на прибрежных землях. Эта проблема не только наносит ущерб домам и сооружениям, но и влияет на жизнь прибрежных жителей. Береговая линия Куанг Нама составляет 125 км и является районом, подвергшимся серьезной эрозии под воздействием гидродинамических факторов, наряду с экстремальными погодными явлениями, влияющими на жизнь людей и ухудшающими местную экономику. ***Цель.*** Используются изображения дистанционного зондирования за 2016–2022 гг. для анализа изменений береговой линии путем интеграции методов (Digital Shoreline Analysis System–DSA) с ГИС, дистанционным зондированием и использованием значений индекса MNDWI для выде-

ления береговых линий. ***Методы:*** метод выделения береговой линии в сочетании с ГИС для расчета изменения береговой линии в сочетании со статистикой штормов для оценки изменения береговой линии. ***Результаты*** показывают, что на всей исследуемой территории эрозия преобладает над осаждением, эрозия сосредоточена в основном в районах Ан Банг, Северный Куа Дай, Дуй Хай и Там Тянь в пределах 3,9–9,2 м/год, в то время как осаждение сосредоточено в основном в районах к югу от Куа Дай и Там Хоа (недалеко от устья реки Чыонг Джанг). Кроме того, результаты анализа изменений береговой линии в районе Куанг Нам в сочетании с данными о штормах, воздействующих на этот район, также показывают положительную корреляцию. Результаты исследований могут предоставить полезную информацию местным органам власти для выработки решений по планированию прибрежных районов и управлению ими.

Ключевые слова: выделение береговой линии, ГИС, эрозия, срастание, Quang Nam, MNDWI

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Introduction

Climate change and sea level rise have exacerbated the impacts of natural disasters, while also increasing the negative effects of inundation and coastal erosion in lowland and coastal areas. Coastal erosion is now a global problem. In addition, sea level rise and negative impacts caused by human activities have been exacerbating the risk of coastal erosion and increasing environmental burden in coastal areas [1]. The shoreline change is determined to be due to the combined influence of natural processes (river morphology, geological structure, flow...) and man-made processes (sand extraction, navigation, construction, building dams, reservoirs upstream…) causing erosion or deposition [2].

Quang Nam boasts a 125 km coastline and numerous estuaries, making it a region with significant potential for tourism development and playing an important role in socio-economic growth. In recent years, due to extreme weather conditions, the rainy season is affected by the northeast monsoon, tropical depression and often storms, these factors have a strong impact on the coastal area of Quang Nam province, causing very serious erosion affecting the lives of people in coastal areas [3]. Therefore, monitoring the shoreline change in Quang Nam is necessary for the sustainable management of the coastline in this area in the context of climate change.

Coastal change monitoring technology is widely applied in the world, at present, there have been many studies using remote sensing data to classify land water from multi-time satellite images combined with geographic information system (GIS), and then superimposed to identify and evaluate shoreline changes. Specifically, the authors in used Landsat images combined with GIS to study shoreline changes in the Göksu estuary from 1984 to 2011 [4]. And the authors of extracted shorelines from multi-temporal (7 ETM+) satellite images combined with GIS to study the change of Marina coastline from 2009 to 2019 [5]. Abdoul et al studied and The research presents the Yanbu coastline change from 1965 to 2019 using Landsat and GIS satellite images [6].

Besides, there have been a lot of studies on shoreline changes done in Vietnam in recent years. Specifically, Nhan et al. calculated the changing speed and trend of the Red River bank from Son Tay to Gia Lam area (Hanoi) using remote sensing images for the period 2007–2016 combined with GIS [7]. Tuan et al. used water indices such as NDWI, MNDWI, AWEI from Landsat 8 remote sensing images to determine water and land boundaries on the West coast of Vietnam [8]. Mau et al. used remote sensing images combined with shoreline survey by DGPS–Promark2, the results show that the erosion rate is higher than the deposition rate in Cua Dai area, mainly due to construction works and impacts of wave [9]. Cham et al. used remote sensing in combination with Delft3D and Mike 11 models to determine the cause and mode of erosion and deposition in Cua Dai area, showing that the process of erosion-deposition occurs in the Northeast winter with the cause of impacts wave motion of the northeast monsoon with wave height of approximately five meters with a frequency of more than 70% [10]. Quang et al. used the Digital Coastal Analysis System (DSAS) technique to statistically calculate the rate of change of the Quang Nam coastline from 1990 to 2019, showing that the Quang Nam coast was eroded and deposited over the past three decades and erosion is most severe in the north of Cua Dai, while shoreline evolution is recorded in the southern region [11]. In the authors used Telemac model combined with hydrodynamic and wave module to study Cua Dai area, showing the main trend of currents and waves towards the south, leading to erosion especially in the northeast monsoon season and deposited in the estuary [12].

In general, the remote sensing method has shown to be effective in monitoring and assessing shoreline

changes over a large scale. Therefore, this paper aims to combine Landsat images with the statistics of storms affecting Quang Nam area, to monitor changes in the coastline of Quang Nam province in the context of climate change in the period from 2016 to 2022.

Research area and methods

Research area

Quang Nam is located at geographical coordinates 14°54’ to 16°13’ North latitude and 107°3’ to 108°45’ East longitude, has a natural area of 10,438 km^2 and a population of 1.46 million people (Fig. 1). The latitude is relatively low, so it receives a rich amount of radiation every year, and it is close to the sea, so it is affected by many different weather and climate factors such as the Northeast and Southwest seasons [13]. In addition, every year storms and low pressure affect Quang Nam at most 2–8 times, less than once a year. The strongest wind speed is from May to November in Tam Ky. In addition, the influence of sea level rise and the impact of climate change have been and are threats to the existence of Hoi An, My Son, and coastal works.

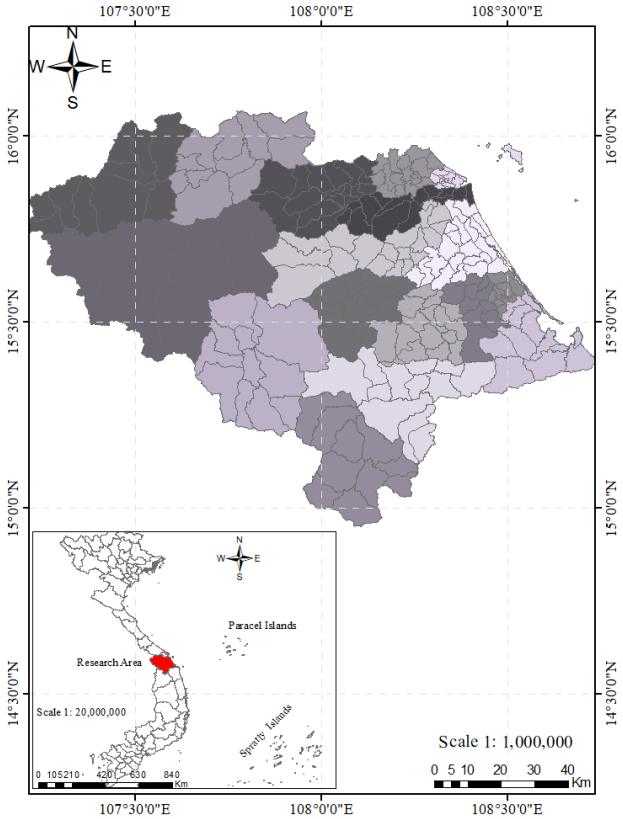

Fig. 1. *Location of Quang Nam province*
Рис. 1. *Расположение провинции Куангнам*

To calculate shoreline fluctuations, we divide the study area into three small areas. Cua Dai area from An Bang to Duy Hai (area 1), Duy Hai to Tam Tien area (area 2) and Tam Tien to Tam Hoa area (area 3) (Fig. 2), in which the area 1 and 3 are the two areas directly affected by the estuary, while area 2 is the area not directly affected by the estuary.

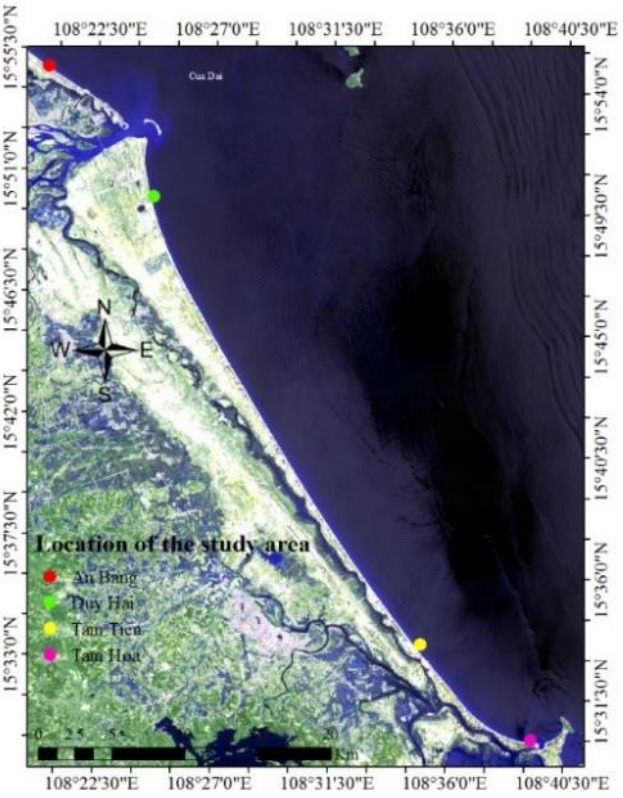

Fig. 2. *Research area*
Рис. 2. *Область исследования*

Data and methods

Data

The remote sensing data used in the study are Landsat 8 images that have been corrected and are referenced to the WGS-84 UTM coordinate system, specifically applicable to zone 48. The image quality is very good and less affected by clouds and fog. Landsat image data source is collected from the website of the United States Geological Survey with a resolution of 30 m. In addition to satellite image data, the study also uses Google Earth image data. This data source is usually very high resolution concentrated in urban areas (under 1m) used to process and compare with shoreline extraction results from remote sensing images. Storm data was collected on the KITAMOTO Asanobu website to compare with the shoreline evolution from remote sensing images (Table 1, 2).

Table 1. *Collection of remote sensing images*

Таблица 1. *Сбор изображений дистанционного зондирования*

Area Об-ласть	Collection of satel-lite images Сбор спутнико-вых снимков	Spatial resolution Пространственное разрешение	Images landsat Изобра-жения
Quang Nam	14/07/2016	30m	LC08
	17/05/2018	30m	LC08
	09/05/2020	30m	LC08
	13/06/2022	30m	LC08

Methods

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

1. *Geometric correction*: for eliminating the deviations that occur during image capture and return the image to standard coordinates that can be integrated with other data sources.
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 MNDWI* (nodification of normalized difference water index): for clarifying two objects – water and land. The MNDWI index is calculated using the formula

$$MNDWI=(Green–MIR)/(Green+MIR)$$

For Landsat 8 OLI/TIRS images:

$$MNDWI=(Band\ 3–Band\ 6)/(Band3+Band6)$$

4. *Using the Reclassify tool in ArcGIS*: for dividing the threshold into two layers, land is the object with value 0 (black) and water has value 1 (white). Due to the limitation of actual survey data, the classification results are corrected with Google Earth images. The shoreline extraction results for each time period are superimposed with the Google Earth image of that time to check the shoreline classification results.
5. *Shoreline change analysis by applying DSAS*: DSAS (Digital Shoreline Analysis System) is a free software integrated with ArcGIS software (ESRI) with the function of analyzing changes in coastline. DSAS generates straight lines that are perpendicular to the baseline and intersect the coastline, which calculates the rate of change of the coastline. The three basic steps of calculating shoreline change rates include:
   - determination of baselines and shorelines;
   - determination of length and distance between the transects (line perpendicular to the shoreline);
   - calculation of the shoreline change rate.

These results are used to calculate and analyze shoreline changes in the study area.

Computation and threshold of the MNDWI

To identify erosion and deposition, it is necessary to separate the shoreline and monitor it over multiple time points. The study focuses on analyzing and processing satellite images based on indicators showing water characteristics. On satellite images, water has strong absorption and low radiation in the range visible to infrared wavelength. The normalized difference water index NDWI is determined based on the green wavelength region reflectance channel (GREEN) and the near-infrared wavelength region reflectance channel (NIR) as shown in the formula:

$$NDWI=(Green-NIR)/(Green+NIR)$$

This method has the advantage of detecting water in areas without built-up soil. However, the results, when using NDWI, are often confused between construction ground and water surface. In order to overcome the above-mentioned shortcomings of NDWI, the author in introduced the nodification of normalized difference water index, MNDWI by shortwave infrared channel – SWIR (band 6) replaces the NIR channel used in the NDWI formula. In this study, Xu also demonstrated the superiority of MNDWI over NDWI by testing both formulations on three different environments, namely the coastal area of Xiamen City, Bayi Lake and Min River of China and gave results with accuracy up to 99% for all three environments. Xu's modified water difference index has the advantage of extracting water in areas with mainly built-up soil or alluvial soils, but has weaknesses in detecting water bodies with low water content high alluvial concentrations and in the waters surrounding the port [14–18]. Therefore, this study used the MNDWI index for shoreline extraction. The overall methodology is summarized in Fig. 3.

Table 2. *Collection of data on storms that directly affect Quang Nam area*

Таблица 2. *Сбор данных о штормах, которые непосредственно влияют на район Куангнам*

Year Год	Storms affect on Quang Nam area Влияние штормов на район Куангнам							
2016	Mirinae	Rai	Sarika					
2017	Talas	Sonca	Doksuri	Damrey	Haikui			
2018	Ewiniar	Son-tinh	Bebinca	Toraji	Usagi			
2019	Mun	Wipha	Podul	Matmo	Nakri			
2020	Sinlaku	Noul	Linfa	Saudel	Molave	Goni	Etau	Vamco
2021	Koguma	Cempaka	Conson	Dianmu	Lionrock	Kompasu	Rai	

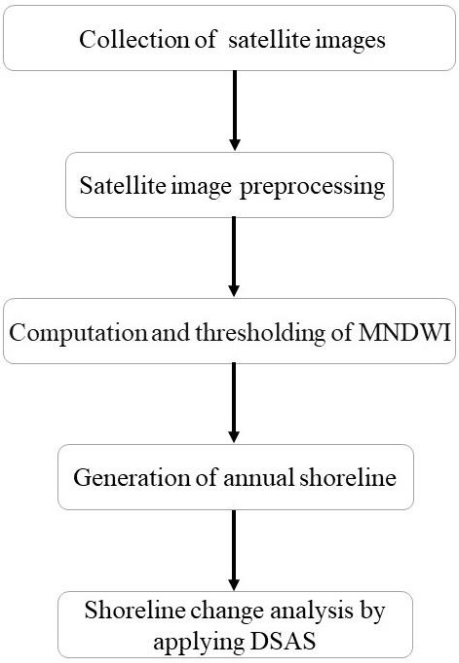

Fig. 3. *Flowchart of the research*
Рис. 3. *Блок-схема исследования*

Results and discussion

Shorelines change of area 1

The erosion situation in Quang Nam province in recent years has become more and more serious, especially in Cua Dai coastal area (Hoi An City). During the Northeast monsoon season, most of the coast in this section is directly affected by the impact of waves causing erosion–deposition. In the area from An Bang to North Cua Dai in the years from 2016 to 2022, the shoreline has erosion and deposition, but erosion is more dominant. Specifically, in the 2016–2018 period, the erosion rate was 9.2 m/year and the deposition was 5.1 m/year, in the 2018–2020 period, the erosion rate reached 4.5 m/year and the deposition rate was 3.2 m/year, and the period of 2020–2022 erosion was achieved 3.9 m/year and deposition 2.2 m/year. Erosion is concentrated mainly in An Bang beach area, north of Dai estuary, but the extent is decreasing over the years. From the south of Dai estuary to Duy Hai, erosion and deposition occur, but to a greater extent than from An Bang to the North of Cua Dai. Specifically, 2016–2018 – erosion 12.5 m/year and deposition 8.1 m/year, 2018–2020 – erosion 7.1 m/year and deposition 6.5 m/year, 2020–2022 – erosion 7.9 m /year and deposition 36.7 m/year. In general, erosion and deposition occur interlaced and concentrated mainly in the South Cua Dai area (Fig. 4–6, Table 3). The embankment section interspersed with embankments of coastal resorts running along Au Co street, from Cua Dai towards Da Nang for about 2 km was strongly eroded.

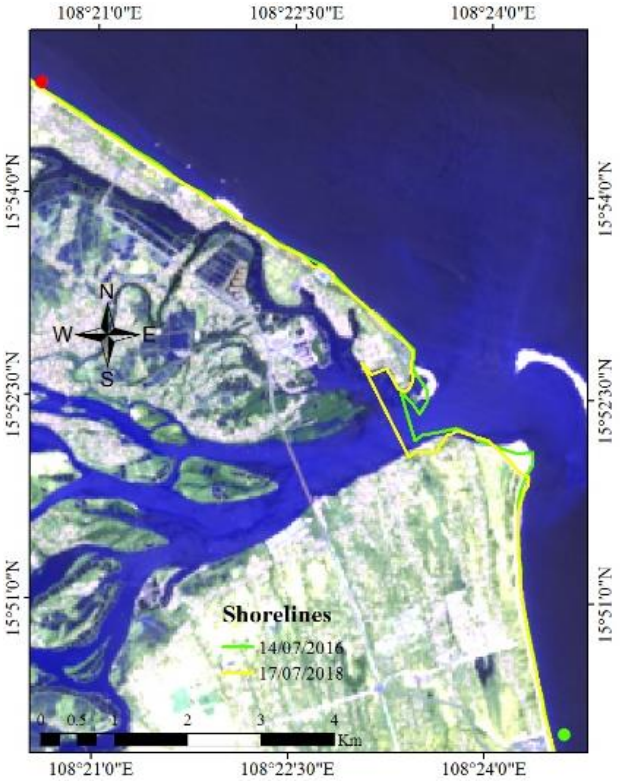

Fig. 4. *Change of the area 1 shorelines, 2016–2018*
Рис. 4. *Изменение береговой линии района 1 в 2016–2018 гг.*

The authors of showed that the erosion rate in the area from Dien Ngoc commune to Bac Cua Dai is about 9.31 m/year, the strongest erosion is about 18.6 m/year in the period 2005–2018, in addition, the trend of erosion also increased linearly over the years [19]. The research showed that all four beach areas: An Bang, Ha My, Cua Dai and Duy Hai (Binh Minh Beach), continued to experience erosion, the highest speed reached 120 m in An Bang area [20]. The authors of show that erosion takes place on a broader and more intense scale in the areas of Duy Hai commune [21]. And the research showed that the lowest value of EPR over the period 1990–2019 is −42.4 m/year, highlighting the most significant erosion at the north of Cua Dai estuary, whereas coastline advance is recorded in the south segment [11].

Table 3. *Erosion and deposition rates in area 1 (m/year)*
Таблица 3. *Темпы эрозии и осаждения района 1 (м/год)*

Period Период	An Bang–North Cua Dai		South Cua Dai–Duy Hải	
	Erosion Эрозия	Deposition Отложение	Erosion Эрозия	Deposition Отложение
2016–2018	9.2	5.1	12.5	8.1
2018–2020	4.5	3.2	7.1	6.5
2020–2022	3.9	2.2	7.9	36.7

Fig. 5. *Change of the area 1 shorelines, 2018–2020*
Рис. 5. *Изменение береговой линии района 1 в 2018–2020 гг.*

Fig. 6. *Change of the area 1 shorelines, 2020–2022*
Рис. 6. *Изменение береговой линии района 1 в 2020–2022 гг.*

Shorelines change of area 2

The coastline from Duy Hai to Tam Tien is in the form of erosion–deposition coast. In general, erosion and deposition occur alternately, but mainly still erosion. This coastal group has also been eroded before, but with low intensity. Due to the construction of the Tam Thanh sea embankment, the beach tends to be more stable, indicating a positive impact on erosion control in the area. Specifically, in 2016–2018, the erosion is 5.3 m/year and the deposition is 5.1 m/year, in 2018–2020, the erosion is 4.3 m/year and the deposition is 3.5 m/year. In 2020–2022, erosion will reach 5.1 m/year and deposition will reach 2.7 m/year (Fig. 7–9, Table 4). The research shows that the coastline, stretching from Duy Hai commune to Tam Tien commune, always has the phenomenon of erosion and deposition, taking place interlaced in space and time. However, in some sections, there are shore protection works but still damaged by waves during storms [21].

Table 4. *Erosion and deposition rates in area 2 (m/year)*
Таблица 4. *Темпы эрозии и осаждения района 2 (м/год)*

Period/Период	Duy Hai–Tam Tien	
	Erosion Эрозия	Deposition Отложение
2016–2018	5.3	5.1
2018–2020	4.3	3.5
2020–2022	5.1	2.7

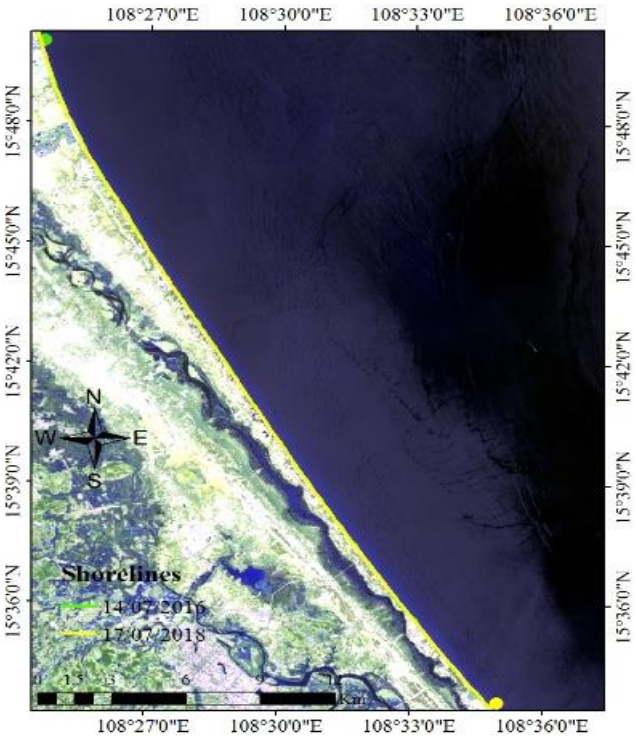

Fig. 7. *Change of the area 2 shorelines, 2016–2018*
Рис. 7. *Изменение береговой линии района 2 в 2016–2018 гг.*

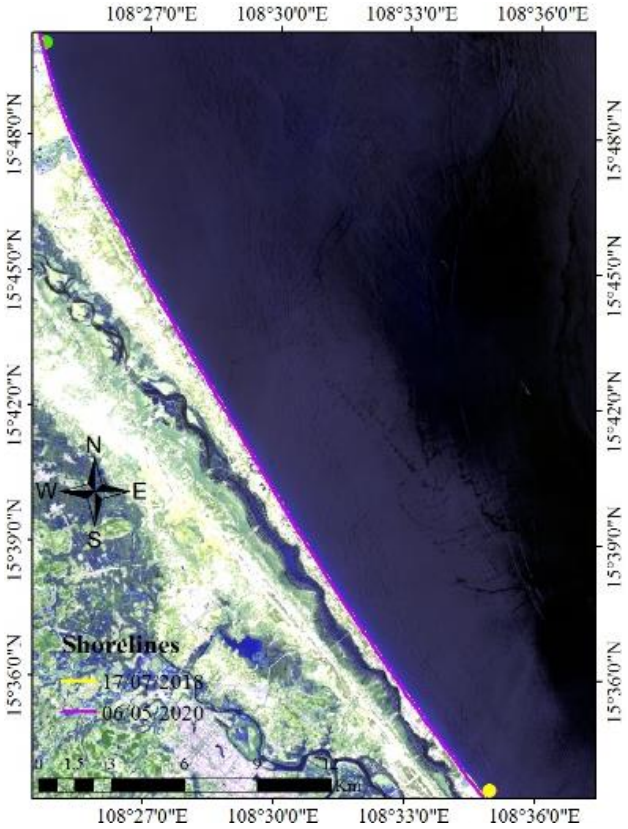

Fig. 8. *Change of the area 2 shorelines, 2018–2020*
Рис. 8. *Изменение береговой линии района 2 в 2018–2020 гг.*

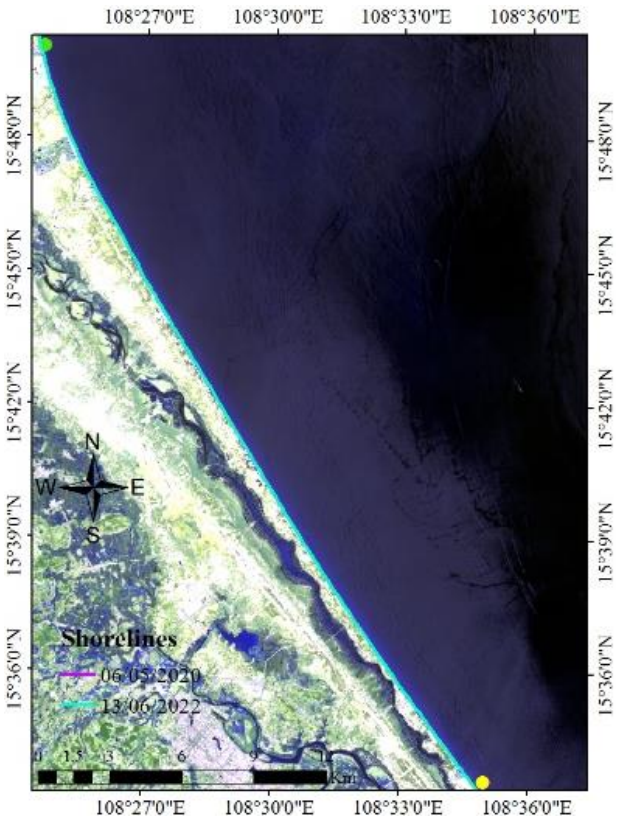

Fig. 9. *Change of the area 2 shorelines, 2020–2022*
Рис. 9. *Изменение береговой линии района 2 в 2020–2022 гг.*

Shorelines change of area 3

In the area from Tam Tien to Tam Hoa, erosion and deposition occurs alternately, but erosion still prevails over deposition. Specifically, 2016–2018 – erosion 4.4 m/year and deposition 4.3 m/year, 2018–2020 – erosion 4.8 m/year and deposition reached 4.6 m/year, 2020–2022 – erosion 5.9 m/year and deposition 3.6 m/year. In general, erosion increases gradually over the years, while deposition decreases gradually over the years, and deposition is concentrated mainly in Tam Hoa area (near the mouth of Truong Giang river) (Fig. 10–12, Table 5). The research shows that the coastal area of Tam Tien (Nui Thanh) has a landslide with a length of about 800 m. The recorded erosion rate ranges from 1.23 to −0.27 m/year [11].

In general, the coast of Quang Nam province always has a tendency of erosion–deposition, alternating between seasons of the year. In particular, in recent years, erosion has taken place with continuous frequency with strong intensity and increasingly fierce level.

Table 5. *Erosion and deposition rates in area 3 (m/year)*
Таблица 5. *Темпы эрозии и осаждения района 3 (м/год)*

Period Период	Tam Tien–Tam Hoa	
	Erosion/Эрозия	Deposition/Отложение
2016–2018	4.4	4.3
2018–2020	4.8	4.6
2020–2022	5.9	3.6

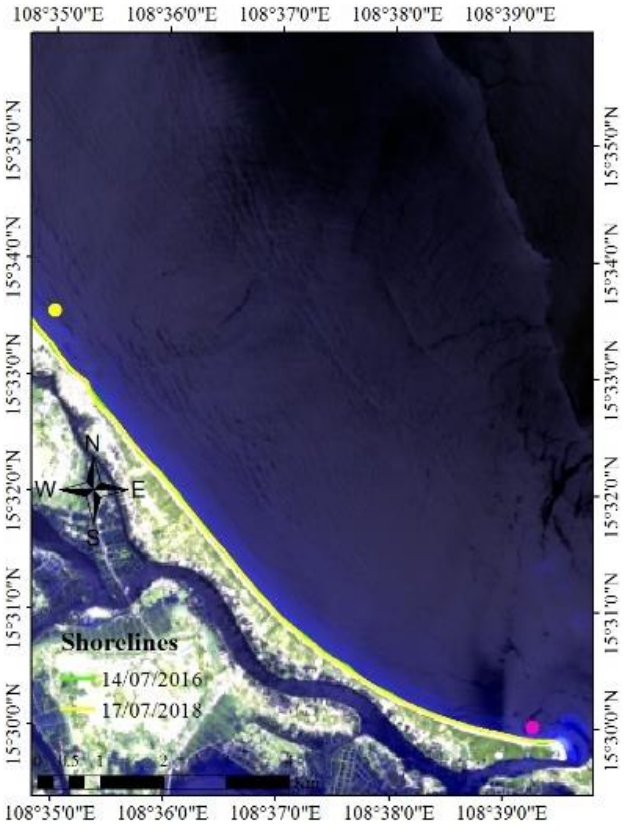

Fig. 10. *Change of the area 3 shorelines, 2016–2018*
Рис. 10. *Изменение береговой линии района 3 в 2016–2018 гг.*

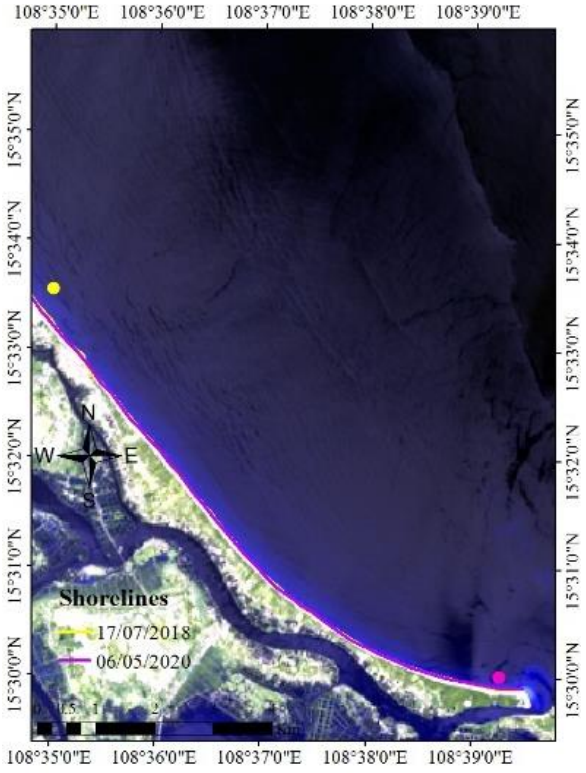

Fig. 11. *Change of the area 3 shorelines, 2018–2020*
Рис. 11. *Изменение береговой линии района 3 в 2018–2020 гг.*

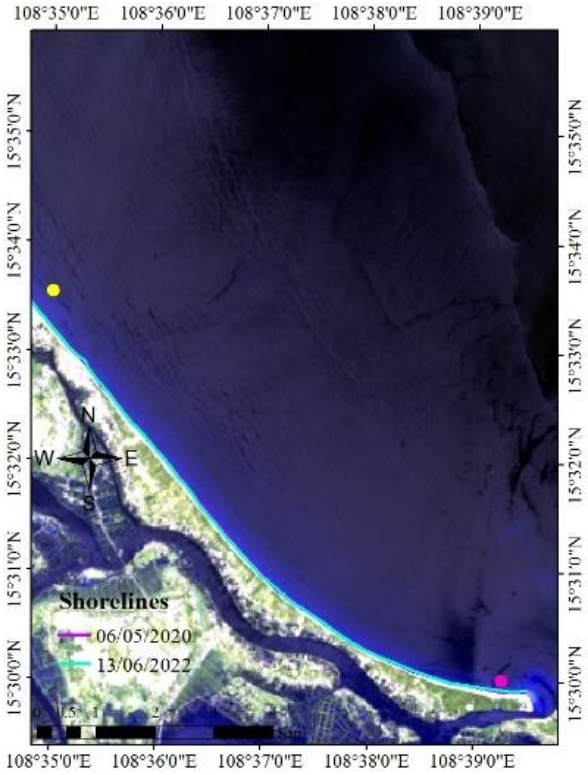

Fig. 12. *Change of the area 3 shorelines, 2020–2022*
Рис. 12. *Изменение береговой линии района 3 в 2020–2022 гг.*

In addition, in the Quang Nam area, during the northeast monsoon season, it often causes large waves and storms are also active during this period, combined with high tide causing flooding and erosion on a large scale. According to statistics in 1961–2014, there were 206 storms and tropical depressions affecting the central region, of which the most were storms from force 8 to 11 accounting for 29% (Fig. 13). The author in also used the SWAN and SuWAT models to calculate the wave height and storm surge of Typhoon Ketsana with the maximum speed of 130 km/h (force 11), showing that the wave height in Quang Nam area has the maximum level of 6.1 m and the maximum storm surge – 1–2 m [22]. In 2016–2021, there were 33 active storms in Quang Nam area, there were 9 storms with speeds above 120 km/h (Fig. 14), showing that the frequency of major storms is increasing adversely affects the coastal area of Quang Nam. Comparison of the results of shoreline erosion combined with storm data also shows a positive correlation. Specifically, in 2016–2018, erosion of 2.0 m/year occurred 8 storms, in 2018–2020, erosion of 2.3 m/year occurs 10 storms, in 2020–2022, erosion of 3.1 m/year occurred 15 storms. Research results are the basis for planning and developing response plans in the context of climate change.

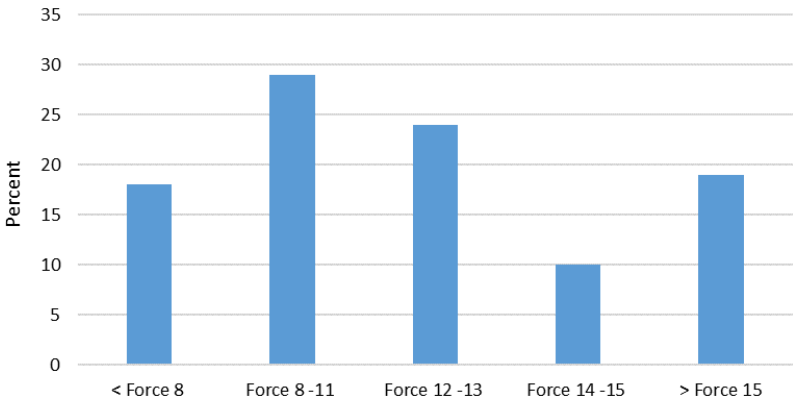

Fig. 13. *Beaufort Wind, 1961–2014 [22]*
Рис. 13. *Ветер Бофорта, 1961–2014 [22]*

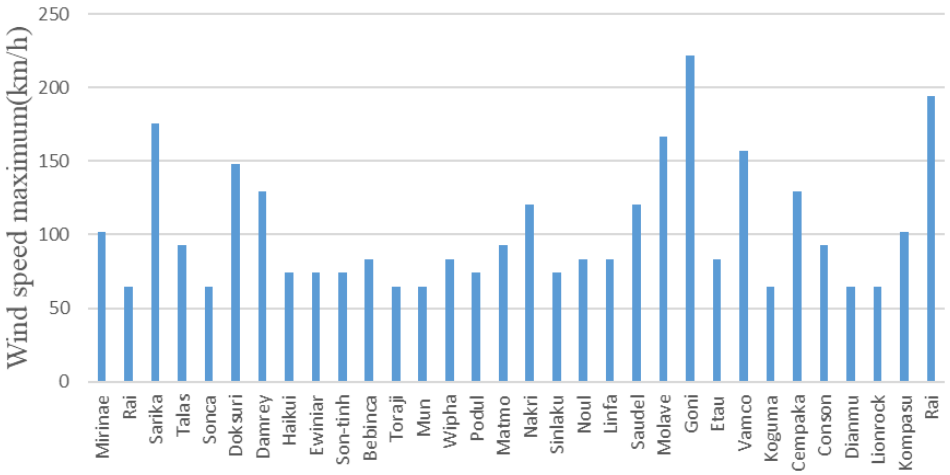

Fig. 14. *Storms affect Quang Nam area, 2016–2021*
Рис. 14. *Штормы, воздействующие на район Куангнам, 2016–2021 гг.*

Conclusions

In the coastal area of Quang Nam province, there are two processes – erosion and deposition, however, erosion is more dominant in all three areas, with high erosion rate mainly in Cua Dai area. In particular, through each period, erosion tends to increase, in 2016–2018, the average erosion rate is about 2 m/year, 2018–2020 – average erosion rate is about 2.3 m/year and average erosion rate in 2020–2022 is 3.1 m/year. In addition, when combined with storm data statistics, it also shows a positive correlation with erosion in this region. Thus, indirectly, climate change has had a very significant influence on coastal erosion in Quang Nam area.

From the results obtained, it is necessary to continue to monitor, research and evaluate the shoreline changes in Quang Nam province in the near future to promptly take measures to prevent erosion to limit the impact on infrastructure and people living in coastal areas.

Limitations and development directions

Satellite images have medium spatial resolution, so higher resolution images are required for analysis, as they increase the reliability of the results.

It is necessary to investigate more real data of shoreline measurement in the study area to compare with the results of remote sensing images, thereby adding reliability to the results of extracting shorelines from remote sensing images.

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