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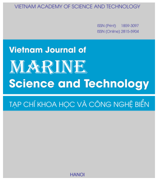

Vietnam Journal of
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TẠP CHÍ KHOA HỌC VÀ CÔNG NGHỆ BIỂN

The application of Google Earth Engine platform to assess the erosion - accretion processes of the estuary and coastal areas of Tra Khuc river, Quang Ngai province, Vietnam

Dao Dinh Cham, Nguyen Van Hong, Nguyen Ngoc Thang, Nguyen Thanh Binh[*]

Institute of Geography, VAST, Vietnam

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ABSTRACT

Along with storms, tides,... human activities have also affected the erosion - accretion process of the coast and estuaries. When global climate change increases the risk of shoreline change in a negative manner, monitoring and quick assessment of this change is of great importance. Google has developed a cloud computing platform, called Google Earth Engine, to effectively address the challenges of big data analysis. This study aims at exploiting and processing multi-temporal satellite images of the Google Earth Engine platform (GEE), combined with topographic data since 1965 to monitor changes in estuary and shoreline of the coastal area of Cua Dai, Tra Khuc river, Quang Nam province during a period of 1965–2021. The analysis results show shoreline changes and hot spots of erosion and landslides along the coast, on both sides of Cua Dai river. After 56 years, the process of erosion - accretion in the river occurs strongly. The eroded riverbanks are located mainly along alluvial plains away from residential areas. Meanwhile, the coast along Cua Dai estuary changes in favor of accretion. However, in recent years, local erosion still occurs in some coastal areas with a length of 0.7–1.2 km in the territory of Pho An - Tan My villages (Nghia An commune). The study shows the potential for directly exploiting and processing large amounts of free satellite image on the GEE for resource monitoring and management applications.

Keywords: Google Earth Engine, Cua Dai - Tra Khuc river, erosion-accretion, shoreline change.

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[*] Corresponding author at: Institute of Geography, 18 Hoang Quoc Viet, Cau Giay, Hanoi, Vietnam. *E-mail addresses:* thanhbinhhtdl@gmail.com

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INTRODUCTION

Cua Dai has a big change process due to erosion - accretion along the banks and accretion of the river and estuary. The changes seem to be frequent and complicated recently, causing many losses in agricultural, forestry and fishery production, especially safety issues for fishermen and boats in the rainy season. According to the monitoring documents of Quang Ngai province, in the downstream area of Tra Khuc estuary, erosion - accretion occurs regularly in the range of about 1,500 m length and 200–300 m width.

Monitoring shoreline changes over the entire area will provide a long-term and general overview of the patterns, state and change of flows. Monitoring data can be linked to the hydrological regime of the whole basin, the activities of exploitation, production and human development. Analysis and evaluation results can provide input data for forecasting models, and landslide warnings in the future.

Until now, the traditional methods of monitoring and observing shoreline often used field measurements to estimate the change. This method has high accuracy, but it is difficult to deploy on a large scale because of the limitations in financial, human and time resources. The application of cloud computing technology in exploiting remotely sensed data to provide an objective and regular view over a large area with appropriate spatial resolution is being considered as a new and modern technical solution, supporting the monitoring of shoreline changes in particular and resource developments in general.

In Vietnam, there have been a number of studies applying remote sensing data in monitoring riverbank erosion of the Tien and Hau river areas. Lam Dao Nguyen et al., (2011) [1] used a combination of radar and optical remote sensing images for landslide assessment in the period 1989–2009; Phan Duc Anh Huy (2015) [2] employed Landsat imagery in assessing changes in the Vam Nao riverbank. Nguyen Ngoc Lam et al., (2010) [3] used SPOT images to monitor changes of the Tien and Hau riverbanks in Dong Thap and An Giang provinces in the period 1995–2003, 2003–2010. Trinh Phi Hoanh et al., (2018) [4] evaluated the change characteristics of the Tien river in the Tan Chau - Hong Ngu area in the period 1966–2015 by using Landsat satellite images. All of the above studies show changes in the shoreline of the river over time. However, the image processing only conducted on a few scenes at a time, either because there is not enough continuous data or it is not possible to process all the images in multiple years due to technical and resource limitations.

GEE shows good ability to extract and process information on satellite images with image classification methods such as Maximum Likelihood (ML), Random Forest (RF), Support Vector Machine (SVM),... Besides, GEE has an open approach, which allows users to develop new methods or algorithms to analyze data using Python and JavaScript programming languages. The initial applications using GEE are: Hansen used GEE to detect degradation and deforestation on a global scale thanks to the multi-temporal LANDSAT image data source [5], Giri used GEE for land cover classification [6], whereas Patel used GEE to estimate forest biomass and carbon [7]. SERVIR Mekong has also started to use GEE in projects related to natural disasters, droughts and floods since 2016.

This study assesses the changes of coastline and estuary in the Cua Dai estuary (Tra Khuc river), Quang Ngai province on the basis of analyzing remote sensing data (Landsat and Sentinel 1) using GEE in combination with topographic and other thematic data.

METHODOLOGY AND STUDY AREA

Study area

The study area belongs to Cua Dai estuary, Tra Khuc river, Quang Ngai province, extending from Tinh Khe commune to Nghia An commune and Quang Ngai city. The study area has about 10 km of coastline and is divided into administrative units as shown in Figure 1.

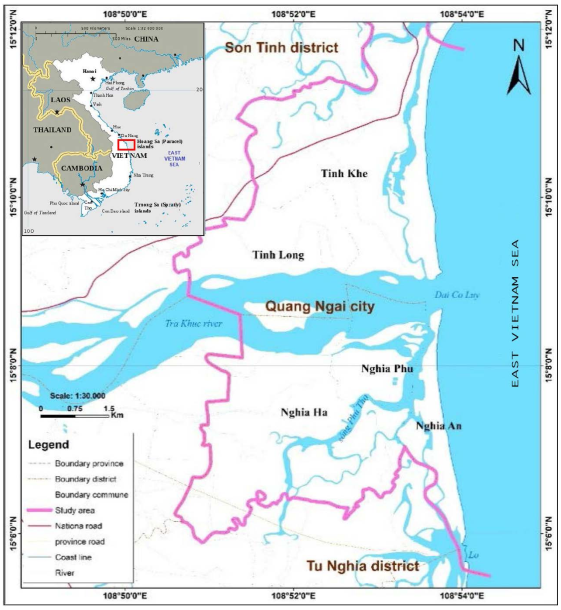


Figure 1. Study Area

The study area located in the tropical monsoon climate region characterized with high temperature and little variations. The study area is the least rainy place in the Quang Ngai province. The rainfall is mainly concentrated from September to December (accounting for 70–80% of the total annual rainfall). Therefore, floods and inundation often occur in this period. Not only that, this place is often affected by storms and tropical depressions. Such climatic conditions have been contributing to the erosion - accretion process of the coastal estuary of the study area.

Data Used

Topographic data

The topographic data used for the study was established by the US Army Mapping Service (AMD-Army Map Service) in 1965 (Figure 2a). These maps were built using stereoscopic method with the following parameters: 1:50,000 scale; 20-m contour interval; zone 49 UTM projection; Elevation landmark: mean sea level in Ha Tien; Plane coordinate system: Indian datum 1960.

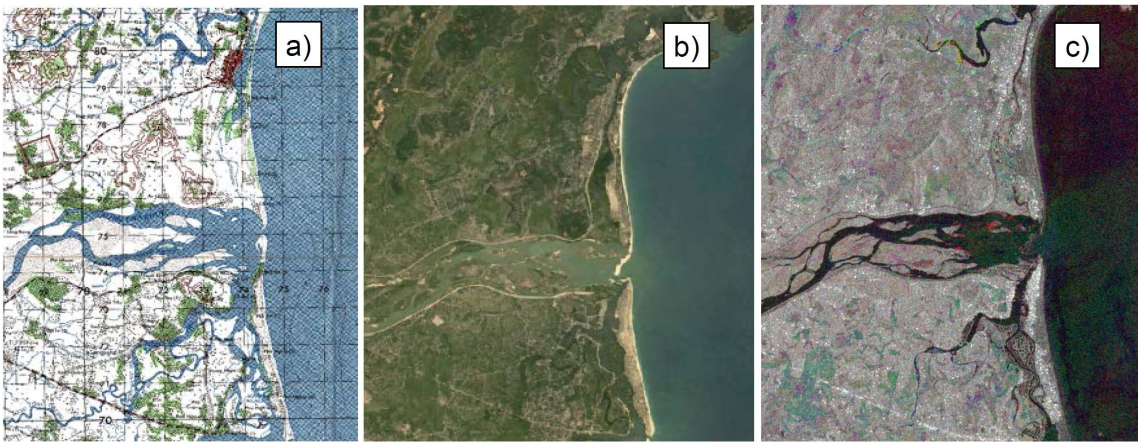
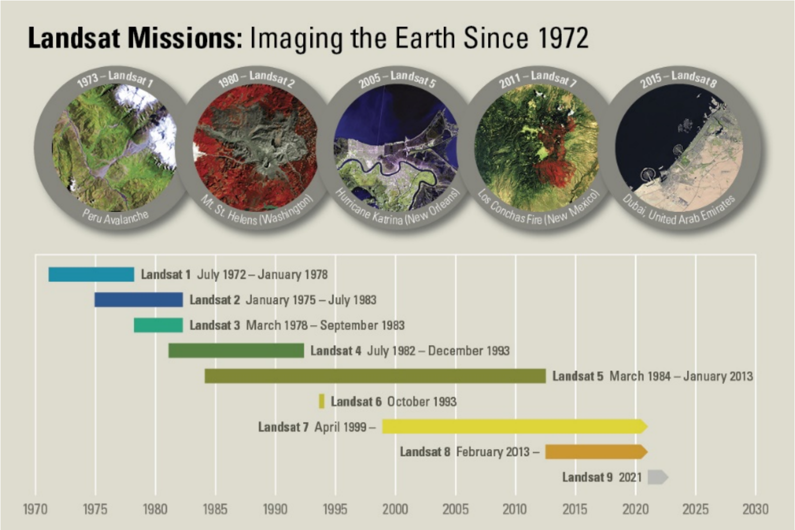


Figure 2. Data used: a) topographic data in 1965; b) optical imagery; c) radar imagery

Satellite data

The study utilized both optical and radar images taken in Cua Dai area from 1975 to 2021. Landsat has many generations of satellites, in which each generation has its own active period.

After searching through the image archive that cover the study area during the research period (1975–2021), the research team decided to use the following imagery: Landsat 2 MSS image with 80 m resolution, Landsat 5 TM image with 30 m resolution from 1975 to 2013. Besides, radar data (not affected by clouds) received via Sentinel 1 satellite starting from 2014 were also used. Sentinel 1 has a resolution of 20 m. Table 1 lists the amount of satellite image data used for the study with basic parameters.



Source: USGS (2022) [8]

Table 1. Satellite data used in this study

No.	Sensor	Period	Number of scenes	Parameters
1	Landsat 2 MSS	1972-1975	18	Sensor: MSS Resolution: 80 m Coverage: 185×185 km
2	Landsat 5 TM	1975-2014	378	Sensor: TM Resolution: 30 m Coverage: 185×185 km
3	Sentinel-1	2014-2021	210	Band C Polarization: HH, VV Resolution: 5×20 m Swath: 250 km

Source: USGS (2022) [8].

Auxiliary data

In addition, the study uses statistics, hydrometeorological and hydrographic data to assess the influence of tides and water levels to ensure more accurate results during the research process.

Methodology

Water extraction using MNDWI

The shoreline can be identified by many different methods [9], in which remote sensing method has been widely used today because of the superiority of data and wide coverage. The basic principle of this method is to separate the water surface from other objects from remotely sensed data. In remote sensing, two main data sources are used: optical and high frequency (radar) data.

Optical remote sensing imagery are images captured in visible wavelengths (0.4–0.76 µm). To separate water from other objects, water related indices such as *NDWI* (Normalized Difference Water Index), *MNDWI* (Modified Normalized Difference Water Index), and *AWEI* (Automated Water Extraction Index),… were employed. On satellite images, water has strong absorption and low reflectance in the visible to infrared wavelength range.

The *NDWI* calculated from the near-infrared and short-wave infrared bands is capable of enhancing the water information to identify and extract it efficiently [10].

However, the *NDWI* is very sensitive to built-up soil. To overcome the shortcomings of *NDWI* in places with dense construction, Xu (2006) [11] built *MNDWI* on the basis of *NDWI* by using *SWIR* band instead of *NIR* band in the formula for calculating *NDWI*.

$$MNDWI = \left(Green - SWIR\right) / \left(Green + SWIR\right) \tag{1}$$

in which: MNDWI stands for Modified Normalized Difference Water Index; *Green* is the Green spectral band in the visible wavelength; *SWIR* is the Short-wave Near-Infrared.

The *MNDWI* index has been verified by numerous studies showing that it is more capable of enhancing the water information, thereby making it possible to extract the water surface more accurately (Figure 3) [12].

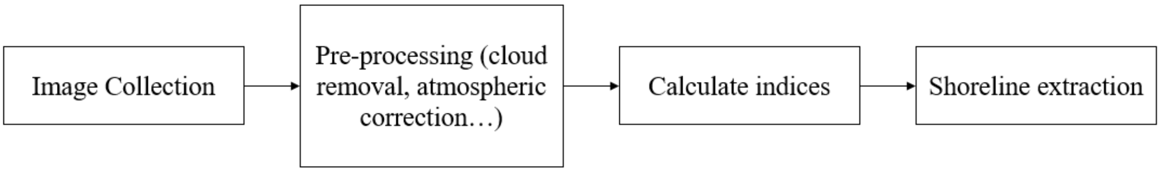


Figure 3. Steps to extract water from optical imagery

Regarding Sentinel-1 image, in this study we use Otsu threshold algorithm (Fig. 4). This algorithm was introduced by Otsu (1979) [13]. Otsu threshold method is based on histogram. By calculating on all thresholds, users can compare and adjust thresholds to finally choose a reasonable threshold for the study area to effectively separate objects.

The Otsu algorithm uses the Canny filter to find and optimize the boundary. The process of finding edges using Canny method can be done through the following 4 steps: Remove noise; Calculate the gradient value; Eliminate non-maximum values; and select the edge of the object.

In addition, the HAND (Height Above Nearest Drainage) filter is also used to threshold the altitude. Values below 30 m in the HAND model will be retained to eliminate bias values obtained from the Otsu threshold procedure.

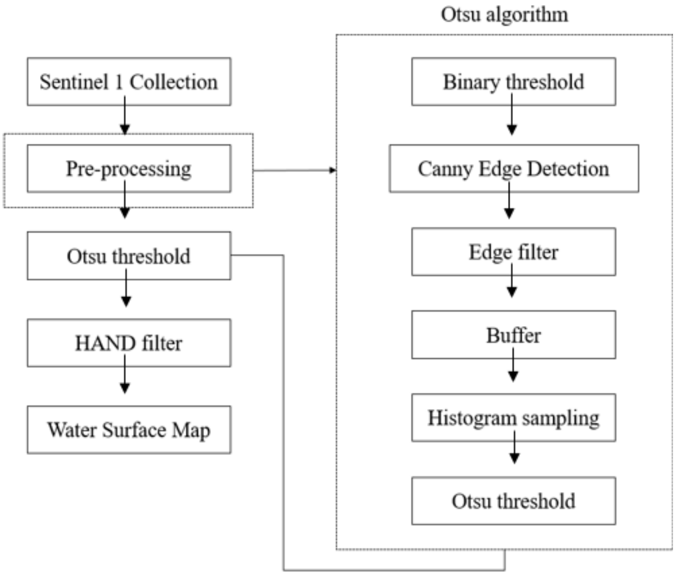


Figure 4. Steps to extract water using Otsu algorithms [13]

Google Earth Engine platform (GEE)

This study used the GEE platform coding for the processing and analysis of multi-temporal satellite image data sets. The scripts are created on GEE's code editor (Earth Engine Code Editor) website through the API application programming interface, with a set of JavaScript programming libraries. These programs send processing commands to the Front-End servers, from where the execution commands are redistributed as more complex query codes to the compute servers. Information processing and analysis are distributed in a network of high-performance computing servers. Therefore, the application of GEE has great strength in directly accessing and processing satellite image data, such as LANDSAT and Sentinel, and returning the results to the user. The scripts include components for processing optical remote sensing images (LANDSAT) and radar images (Sentinel-1). The implementation steps emphasize on extracting the surface water of the images, then combining to extract the surface water bounded by the riverbank. Finally, time series analysis was conducted to assess riverbank changes.

Calculate the speed of erosion - accretion

The study used DSAS (Digital Shoreline Analysis System) tool to calculate the rate of erosion - accretion. The DSAS tool is integrated in the ArcGIS software. The calculation and analysis of the shoreline is carried out as follows: identify the baseline and the calculated shorelines; Create transect lines perpendicular to the shore (transect); Calculate the shoreline change rate.

Based on shoreline data after digitization, the study uses the start-end point (EPR) method to analyze the results for the periods 1965–1975, 1975–1988, 1988–1995; 1995–2005; 2005–2015; 2015–2021 and using linear regression (LRR) during the period 1965–2021.

Research workflow

The GEE image processing to extract riverbank information includes main steps such as: access the image archive, pre-process the images, calculate water index, shoreline/riverbed extraction, and assess the change (Figure 5). Querying the Landsat and Sentinel-1 image collection in GEE, the advantage when querying the image collections in GEE is that the data sources are queried directly from the database and processed online on Google's system, almost not using the resources of the user's computer. A single line of code in the JavaScript language can replace a multiple day load. Time-based image filtering functions, spatial image collection filtering functions can be set up in a few lines of codes.

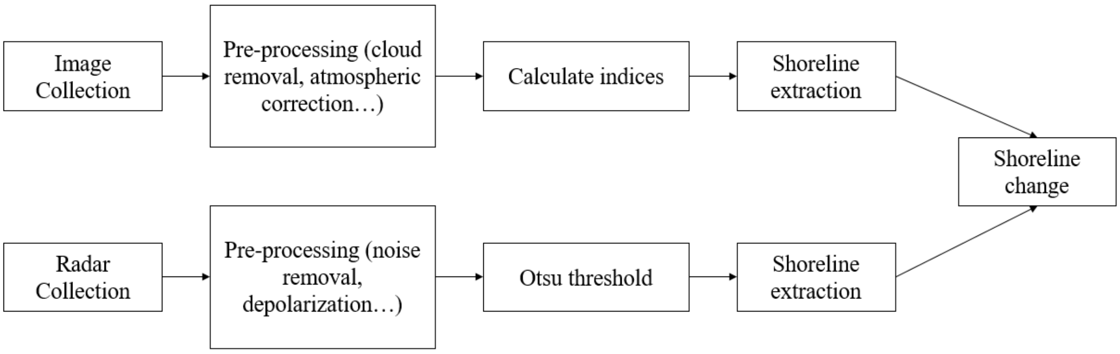


Figure 5. Water extraction in the study area using satellite data

The results of the water surface classification at different time using optical imagery (Landsat 2, 5) and radar imagery (Sentinel-1) were converted to vector. Statistical analysis is been automatically implemented in GEE. Analysis results, images and maps obtained during processing can be downloaded to personal computer or exported to a Google account for online storage, which is very convenient for exploitation and sharing. Raster data will be exported in geotiff format and vector data are saved in kml or shapefile format.

RESULTS AND DISCUSSION

Results

Results of processing satellite images in GEE platform

The entire process of optical satellite image processing (Landsat 2 MSS, Landsat 5 TM) as well as water surface extraction is executed on the GEE platform by programmed scripts. The results of the water extraction from the annual *MNDWI* images are shown in Figure 6.

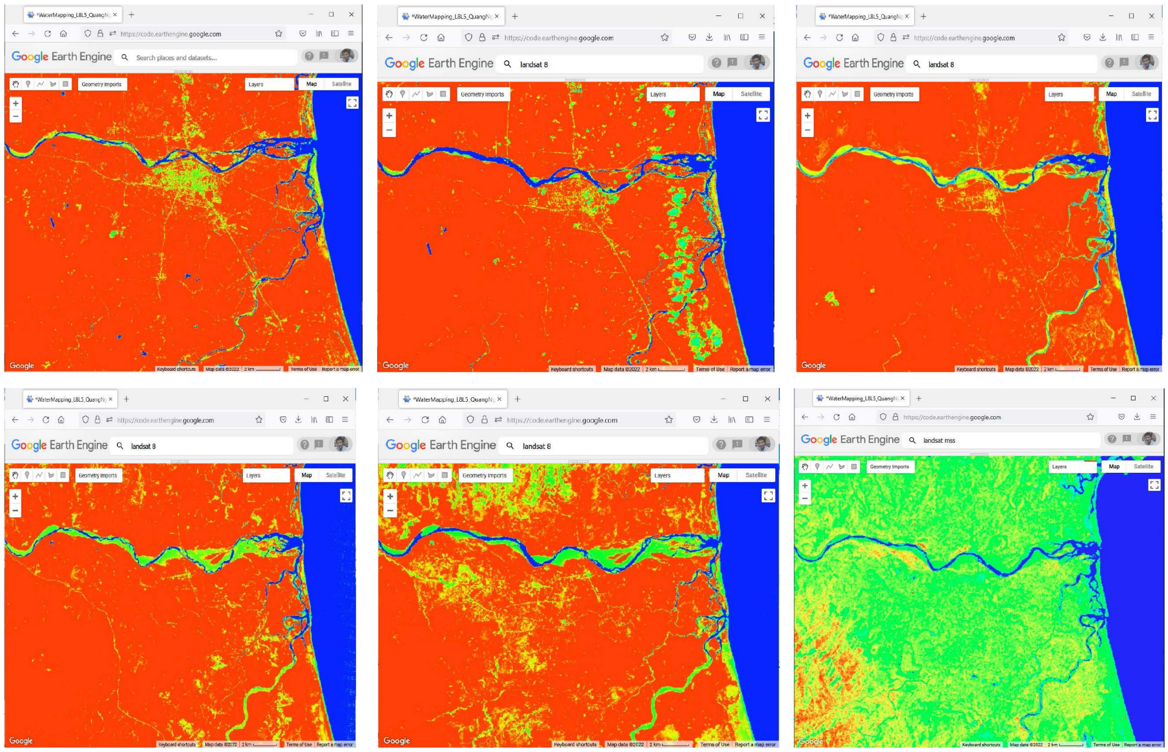


Figure 6. Processed Landsat images in the year 2021, 2015, 2005, 1995, 1988, 1975

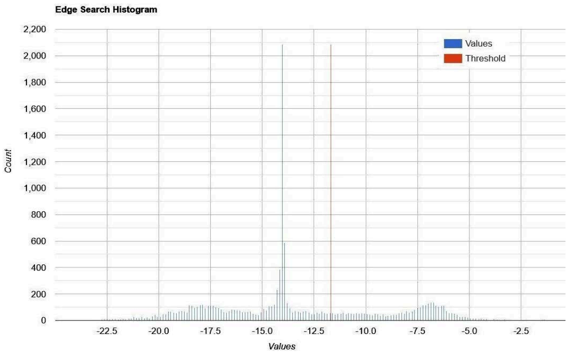


Figure 7. Otsu value thresholding for Cua Dai area

From Figure 6, it is easy to see that the water surface is separated from other objects. The water in the river reflects the current state of the riverbank at the time of image acquisition. Water surface area is the image pixels with *NDWI* value greater than 0, which are easily separated and isolated from the images.

Similar to optical satellite data, the entire process of Sentinel-1 images processing as well as water surface extraction is also executed on GEE platform by programmed scripts and processing results are shown in Figures 7 and 8.

The Sentinel 1 processing results are shown in Figure 8d. It can be seen that the water surface areas appear very differently from other objects on the image. Radar waves are reflected when encountering the water surface, only a small part of the scattered signal returns to the receiver, so the water surface has low decibel value pixels and appears as a dark area in the image. For each Sentinel-1 image scene, the threshold technique helps to separate water surface pixels while also separating non-water pixels.

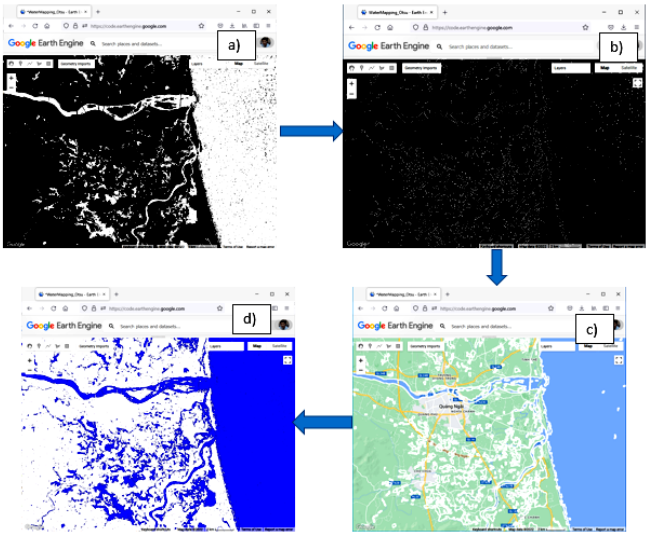


Figure 8. Sentinel-1 image processing results of the study area on GEE: a) Sentinel 1 image after binary thresholding; b) Sentinel 1 image after Canny edge detection; c) Sentinel 1 image after Edge Buffer; d) Sentinel 1 image after separating soil and water

Riverbank change assessment of Cua Dai estuary, Tra Khuc river, Quang Ngai province in the period 1965–2021

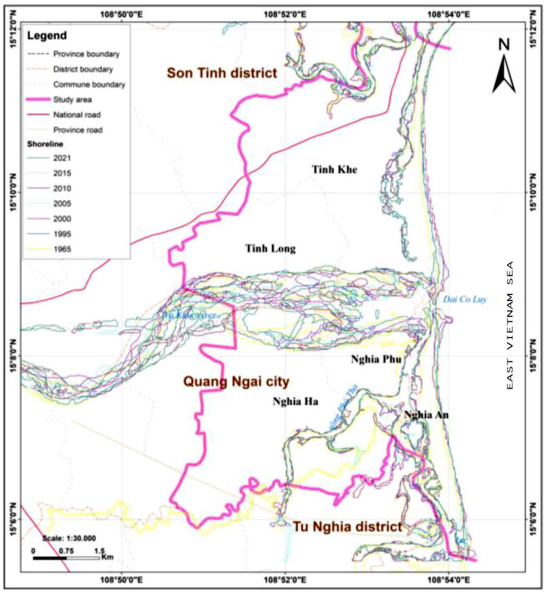


Figure 9. Shoreline dynamics in the Cua Dai estuary, Tra Khuc river, Quang Ngai province

All water surface data is extracted from optical satellite images (Landsat 2 MSS, Landsat 5 TM) and radar satellite images (Sentinel 1) were converted into raster and vector formats. The next step is to process and edit riverbank change maps in the study area. The results are shown in Figures 9 and 10.

The water surface data extracted from remote sensing data was used GIS tools to analyze the accretion and landslide areas, giving us the results of changes in riverbank, coastline and spatial distribution maps. The results show the degree of riverbank change in the whole study area from 1965 to 2021 (Fig. 10).

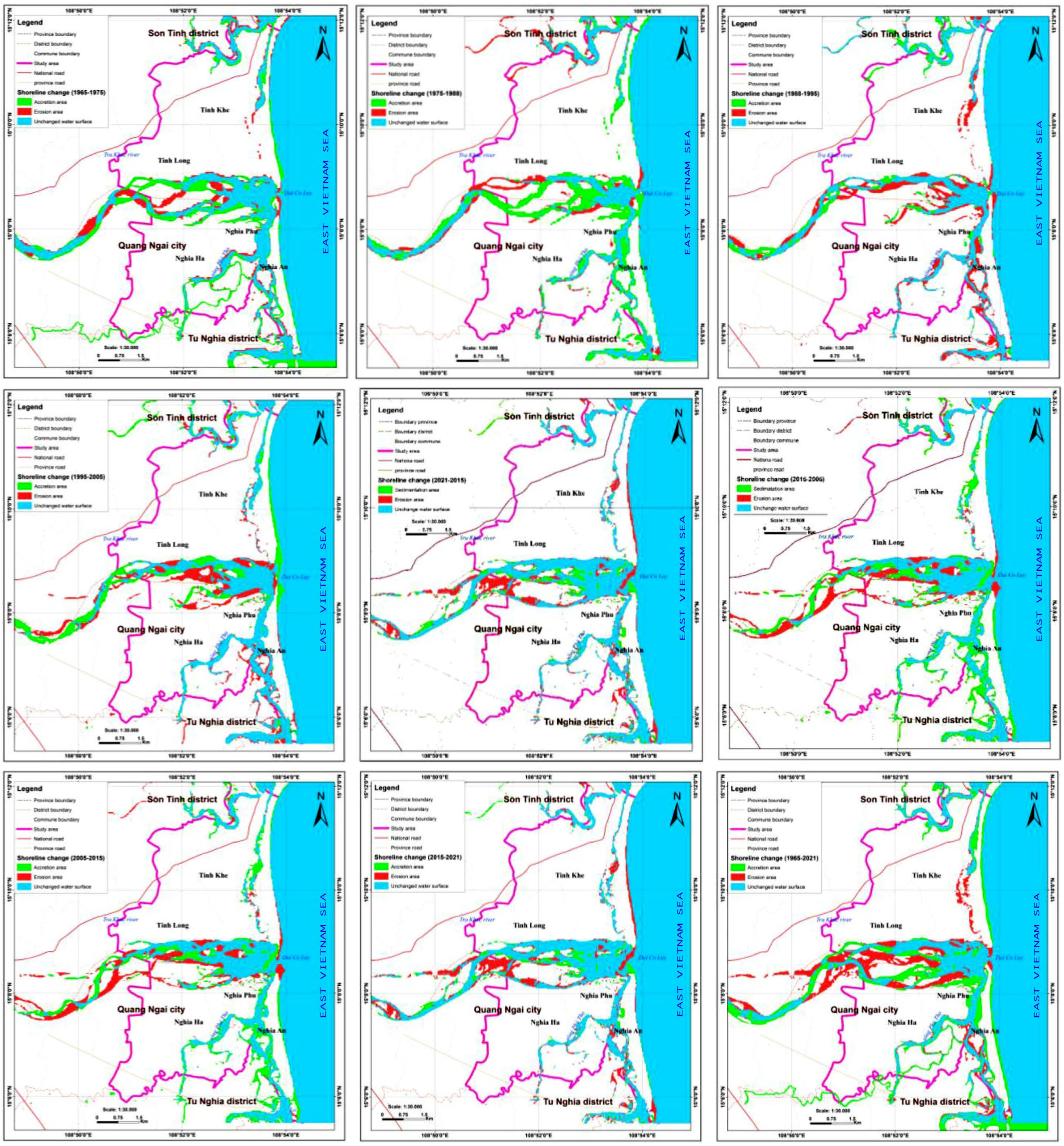


Figure 10. Shoreline change map of Cua Dai, Tra Khuc river during the period of 1965–2021, derived from satellite imagery

Speed of changes and trend

We then assessed erosion-accretion speed and width using DSAS tool. Calculated results are shown in Tables 2 and 3.

Results and discussion

The change of riverbank is a completely normal process according to natural laws and normally this process must take place in balance (the accretion versus the erosion). The results in Figure 10 and the statistics in Table 2 show that the trend over the past 56 years in the study area shows this rule exactly in the river part inside the estuary. This finding is in line with some previous studies of the same study area [14–16]. These studies show that in the absence of special events (high flood, big storm,…), this area have experienced both erosion and accretion in the period 1965–2021. Erosion and accretion changed the river bed many times during the study period, especially the mudflats in the middle of the river, such as Go Nong Dan, Go Ot. After the year 2010, the landslides only occurred in local areas, accretion starts to occur in many locations inside the river. This is a positive result of the dike system along the sea.

Table 2. Statistical data of the riverbank and shoreline erosion-accretion of Cua Dai estuary, Tra Khuc river, Quang Ngai province in the period of 1965–2021

Period	Area (ha)		Average speed of erosion (ha/yr)	Average speed of accretion (ha/yr)
	Erosion	Accretion		
1965–1975	162.94	287.66	16.29	28.77
1975–1988	137.48	377.26	10.58	29.02
1988–1995	299.69	82.38	42.81	11.77
1995–2000	230.34	146.11	46.07	29.22
2000–2005	149.64	160.3	29.93	32.06
2005–2010	131.17	156.54	26.23	31.31
2010–2015	135.82	196.86	27.16	39.37
2015–2021	194.16	90.53	32.36	15.09

Table 3. Statistical data of erosion-accretion of the study area during the period of 1965–2021 (Unit: m)

Location	1965	1975	1988	1995	2000	2005		2010	2015	2021
North bank	0	151.28	-121.3	-82.86	341.58	57.81		38.32	-96.76	-94.36
South bank	0	85.31	64.01	-154.7	345.27	91.17		74.21	-58.23	-38.95

Meanwhile, the estuary area is always in a state of accretion, even completely filled up at many times of the year, greatly affecting the economic activities of the local community. The situation of “sand bars” blocking the river mouth, hindering traffic, often occurs (Figure 11).

Regarding the coastline outside the estuary, accretion is the main change on both sides of the river mouth, the coastline has shifted away from 1965 in some places by 100 m. This trend continued from 1965 to 2005 and was strongest in the period of 1995–2005. However, this trend is changing, the coast has been eroded since 2005, mainly in the north of the river mouth. Changes in the shoreline have taken place strongly in recent years, greatly affecting the ecological environment as well as people’s lives in the riparian areas.

This feature is due to the characteristics of the climate and topography here. In the dry season, the water flow from the river is small, and the amount of sediment transported from the river to the sea is negligible. Therefore, waves and tidal currents are the main factors that contribute to the formation at the estuary.

After 2–3 years if there is no major flood in the river, the possibility that alluvial deposits between the river and the estuary will occur is high. In the rainy season, when floods occur. The mud and sand in the riverbanks, river beds and in the sand dunes on both sides of the estuary are eroded, drifted and pushed into the sea. Part of the sediment is deposited in the dunes blocking the mouth, and a part is deposited in the beaches adjacent to the estuary. Through analysis over a long period, the years without major floods are the years with insignificant change in the estuary width, even narrowing in the next dry season. Thus, waves and tidal currents are the driving factors that narrow the estuary. On the contrary, flood currents are the driving factors that widen and help maintain the estuary. These factors affect the estuary alternately and change between seasons of the year.

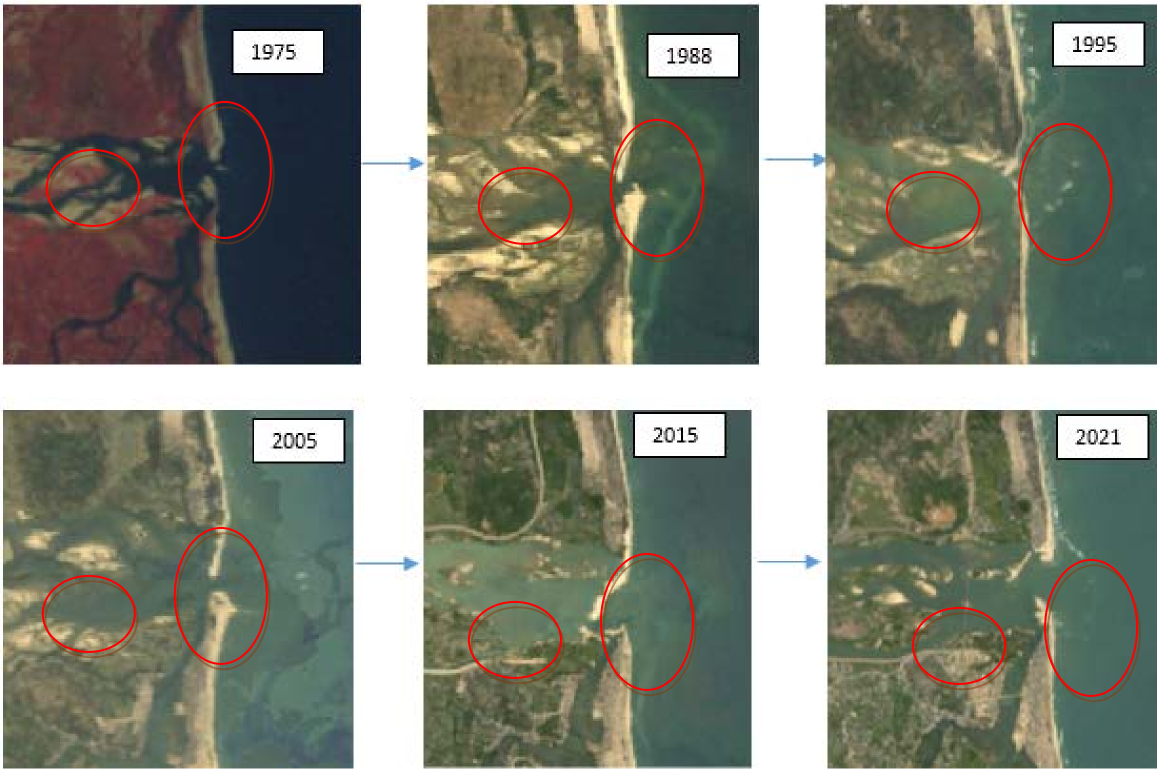


Figure 11. Cua Dai estuary change during the period of 1975–2021

Calculation results of the rate of erosion - accretion show that over the past 56 years, accretion is more than erosion in the study area. The accretion process is relatively stable over a length of nearly 6 km, the accretion area is 30–50 m wide. In particular, the process of landslides focuses on years with heavy rain, storms and floods. Meanwhile, erosion occurs locally in some sections of the coast with a length of 0.7–1.2 km in the territory of Pho An - Tan My villages (Nghia An commune) with a width of 10–30 m and a maximum up to 80 m. The coastal erosion - accretion takes place strongly in the period of northeast monsoon. The phenomenon of the riverbed having strong accretion and becoming an alluvial hazard occurred also in Cua Dai estuary. The estuary deposition has caused difficulties for boats and ships to enter and exit and especially hinder the drainage of flood water to the sea.

Figure 12 shows the change of erosion and accretion area in Cua Dai estuary in the period 1965–2021. From Figure 12, it can be seen that the erosion in the period 1965–1995 was strong, gradually decreased until 2015 due to the positive impact of construction works.

However, from 2015 up to present, this phenomenon tends to increase on both sides of the estuary in areas without embankments. Meanwhile, the accretion process tends to decrease gradually during the whole study period, this process is directly related to the flood process of Tra Khuc river.

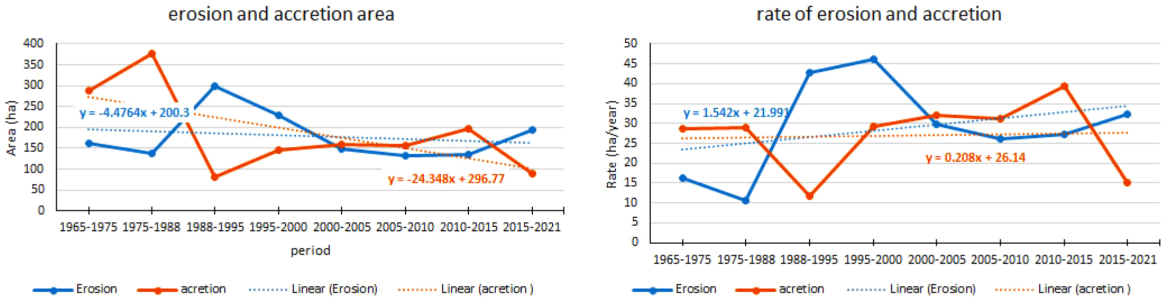


Figure 12. Erosion - accretion of the Cua Dai region in the period 1965–2021

The entire processing of remotely sensed data as well as water surface extraction is done automatically on GEE's platform. Hundreds of quickly-processed satellite images demonstrate the advantages of GEE application in monitoring riverbank changes. Fast processing speed, taking advantage of free and official data sources, and always being updated with the latest data are the biggest advantages of the system.

CONCLUSION

The study has established the flowchart for processing, calculating, extracting and monitoring coastline/estuarine changes from optical satellite image data (Landsat 2 MSS, Landsat-5) and radar satellite images (Sentinel-1) on GEE's platform and evaluate the coastal changes of Cua Dai estuary, Tra Khuc river, Quang Ngai during the period of 1965–2021. The analysis results show the trend of coastal/estuary changes and especially the current status of landslide and accretion in the study area as follow:

The banks of the downstream sections of the Tra Khuc River fluctuated strongly due to large floods occurring in 1998, 1999 years. The Cua Dai coast changes at low amplitude, favoring accretion. Local erosion occurred in some coastal sections with a length of 0.7–1.2 km in the territory of Pho An - Tan My villages (Nghia An commune);

The phenomenon of coastal erosion - accretion takes place strongly in the period of northeast monsoon. The phenomenon of the river mouth with strong accretion and becoming an alluvial hazard also occurred in Cua Dai. The estuary deposition has caused difficulties for boats and ships to enter and exit and especially hinder the drainage of flood water to the sea.

In general, the research results show a general trend of erosion - accretion in the Dai Co Luy estuary area of Tra Khuc river, Quang Ngai province. However, because the satellite data used has medium resolution (80 m and 30 m), the calculation results are limited with small erosion-accretion areas.

The method applied in this study is simple, effective and has high accuracy for the area with the size of landslide and accretion areas larger than 30 m. For smaller areas, it is possible to use higher resolution remote sensing data (SPOT 6.7 Worldview, Orbview, Pleiades,…) and in combination with field survey data.

Remote sensing data as well as image processing technology on cloud computing in general and on GEE in particular show great potential for application in shoreline assessment, monitoring systems, and monitoring of environmental resources. If satellite image database systems or near real-time environmental monitoring systems are quickly integrated into GEE's platform, this will be an effective environment for processing and analyzing territory management as well as scientific research.

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