ANALYZING RIVER ESTUARY CHANGES USING REMOTE SENSING IMAGES, A CASE STUDY OF NHAT LE RIVER OF QUANG BINH PROVINCE

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ABSTRACT

There is a strong linkage between river morphology and river floods. Hence, this study focuses on detecting changes in the shoreline of the Nhat Le river mouth by using a series of optical satellite images (Landsat and Sentinel-2). For achieving our study goal, we applied shoreline interpretation technology by performing models integrated in DSAS software provided by United States Geological Survey added in the ArGIS platform. Inside the models, image indies, water thresholds and spatial analyses have been implemented to evaluate shoreline changes. The shoreline variations were assessed by calculating its changing rates driven by erosion and accretion processes in each 5-year periods from 2010 to 2020. The changing rates were quantified using three functional statistical parameters in DSAS, which are the evaluation of end point rate (EPR), Net Shoreline Movement (NSM), and Linear Regression Rate (LRR) statistics that indicated the variability of Nhat Le river mouth during the study period. Thereby, the advantages and the reliability of the study method were revealed and able to support the assessment of shorelines changes in terms of time and cost efficiency.

PHÂN TÍCH BIẾN ĐỘNG CỬA SÔNG SỬ DỤNG ẢNH VIỄN THÁM, NGHIÊN CỨU ĐIỂN HÌNH TẠI CỬA SÔNG NHẬT LỆ, TỈNH QUẢNG BÌNH

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TỪ KHÓA

Landsat
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Xói mòn
Bồi tụ

TÓM TẮT

Biến động hình thái sông có mối liên hệ mật thiết với lũ lụt. Do đó, nghiên cứu này tập trung vào việc phát hiện sự thay đổi, biến động của đường bờ cửa sông Nhật Lệ bằng cách sử dụng chuỗi ảnh vệ tinh quang học (Landsat và Sentinel-2). Với công nghệ giải đoán đường bờ thông qua phương pháp tính toán chỉ số, phân ngưỡng ảnh và phương pháp phân tích đánh giá biến động đường bờ nhờ tính toán từ các mô hình được tích hợp trong phần mềm DSAS cung cấp bởi Cơ quan khảo sát địa chất Hoa Kỳ được tích hợp trong môi trường ArcGIS. Biến động đường bờ được đánh giá thông qua chỉ số biến động sau chu kỳ 5 năm bao gồm quá trình xói lở và bồi tụ từ năm 2010 đến 2020. Chỉ số biến động đường bờ được lượng hóa sử dụng 03 biến phân tích chức năng trong DSAS là đánh giá tỉ lệ điểm cuối EPR, Độ dịch chuyển của đường bờ NSM và Thống kê tỷ lệ thay đổi hồi quy tuyến tính LRR đã làm sáng tỏ sự biến động của đường bờ cửa sông Nhật Lệ trong giai đoạn nghiên cứu. Kết quả nghiên cứu cho thấy ưu điểm, độ tin cậy của phương pháp nghiên cứu, thấy được khả năng hỗ trợ đánh giá những thay đổi vùng ven bờ hiệu quả, kịp thời.

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1. Introduction

According to the report of the Ministry of Agriculture and Rural Development (MARD), Vietnam's coastline from Mong Cai (Quang Ninh) to Ha Tien (Kien Giang) has a total length of 3,260 km [1]. In average of 20 km of coastal line, there is a river mouth. Especially, the central coastal areas in Vietnam are unstable due to the morphology of low slopes (from 1/5 to 1/500) and large number of sand dunes. Along the central coastal course, there are mountain ranges facing to the sea, creating large bays, alternating terrain between narrow plains and coastal sand dunes. The river system is short, sloping unevenly, with highly difference between up-stream and down-stream. These natural features create favorable factors for socio-economic development and security – defense. However, the river system characteristics also prone to many potential risks of coastline morphology changes leading to higher flood damages.

The central coastal provinces are located in the areas of strong storms and super typhoons landing. Averagely, these areas are directly affected by five tropical typhoons annually. Particularly, from September to November 2020, serious and large-scale landslides were caused by a series of eight storms coming from the East Sea, and six of them caused the landslides directly in the central region leading to catastrophic damage to the area. In addition, coastal erosion in the central Vietnam often occurs at large scale and in a short of time. According to preliminary 2020 statistics of MARD, there were 2,229 coastal erosion points across the country with a total length of more than 2,837 km. Herewith, coastal provinces from Nghe An to Binh Thuan accounted for 815 points on 1,200 km coastal line [1].

River morphology changes driven by erosion and accretion of riverbank/bed and coastlines have been interested by most countries in the world. Coastlines are a part of the river estuary and defined by Genz et al. (2007) and its characteristics represent coastal erosion and accretion [2]. Importance of the estuary and coastline have been drawn much attention such as studies of Addo and Kufogbe (2011) [3]; Kabuth et al 2014 [4]; El-sharnouby et al. 2015 [5]... In Vietnam, there have been various studies in this field determining the causes of river banks and shoreline degradation and proposing effective prevention proposals. Some examples are; Tran Thi Van et al (2008) studied and discovered shoreline changes for sustainable management of the coastal area of the Mekong estuary [6]; Tran Thi Van et al (2014) applied remote sensing and GIS to detect changes in the mangrove coastline at Cape Ca Mau, Vietnam [7]; Bui Thi Kien Trinh, Nguyen Manh Cuong (2019) analyzed coastal changes in Nha Trang, Khanh Hoa province [8]. Some research works have obtained results contributing to the corrections of Vietnamese estuaries and coasts driven by natural erosive and accretive force.

An advantage of remote sensing technology is an ability to continuously capture images providing a series images of the Earth's surface over a long period of time [9]. Remote sensing images stored in large servers often offer an unique ability to extract of the shoreline changes in the past and near real-time [10]. Analysis of shoreline changes information in past and at present and related information enables an assessment of future change trends. In terms of time and cost efficient, remote sensing data seems to be more effective compared to traditional approaches of in-situ measurement particularly for large study areas. On the other hand, optical remote sensing data are effected by clouds, aerosols and defended on the solar light [11], hence, the number of good quality images are reduced. In addition, higher temporal and spatial resolution remote sensing data are often commercialized and not available to a large number of researchers. In this study, we will experiment to study and analyze the changes in the shoreline of Nhat Le Estuary - Quang Binh using long-free Landsat and Sentinel data series(2010 – 2020) provided by United States Geological Survey (USGS) and European Space Agency (ESA). The shoreline changes are assessed by applying the interpretation technology, index calculation, image thresholding. A Digital Shoreline Analysis System (DSAS) software provided by USGS added in ArcGIS will facilize the EPR (End Point Rate), Net Shoreline Movement (NSM), and Linear Regression Rate (LRR) methods of analyzing the shoreline changes.

2. Materials and Methods

2.1. Study area

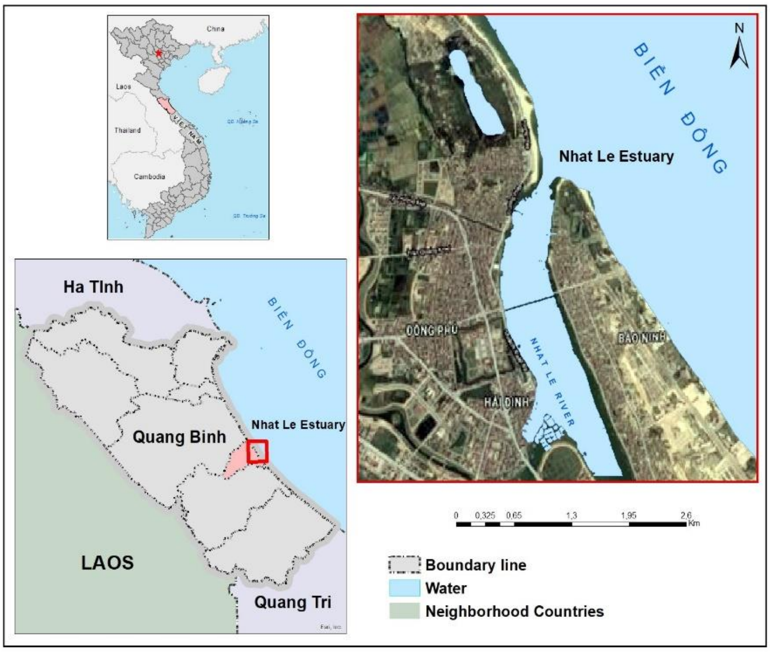

Figure 1. *Study area – Nhat Le River Estuary*

This study focuses on only the Nhat Le river estuary, the confluence of Kien Giang river and Long Dai river - Quang Binh province (Figure 1). The basin terrain is strongly fragmented lead to a density river network of 0.84 km/km^2 [12]. The lower part of the river basin is a favor condition of water concentration. Therefore, it is extremely prone to floods in the rainy season. In recent years, Nhat Le estuary has been accreted due to the development of sand dunes in the south of the river mouth, obstructing flood drainage and causing erosion in the north side, causing risks to the economic works of Dong Hoi city. There is a concentration of economic establishments, large urban areas and the capital of Quang Binh province. Therefore, the fluctuations of this estuary have a particularly important influence on the economy, socio-politics and security and defense. That is the seasons for us to choose the Nhat Le estuary for a presentative case study.

2.2. Data

Table 1. *Details of satellite dataset (acquired via https://earthexplorer.usgs.gov/)*

STT	Satellite data	Path/row	Times	Resolution (pixel size) (m)
1	Landsat 5 - TM	126/48	12/07/2010	30
2	Landsat 5 - TM	126/48	13/10/2011	30
3	Landsat 8 - OLI(TIRS)	126/48	17/05/2013	30
4	Landsat 8 - OLI(TIRS)	126/48	24/08/2014	30
5	Landsat 8 - OLI(TIRS)	126/48	01/08/2015	30
6	Sentinel-2	NA	25/07/2016	10
7	Sentinel-2	NA	09/08/2017	10
8	Sentinel-2	NA	30/06/2018	10
9	Sentinel-2	NA	11/04/2019	10
10	Sentinel-2	NA	15/05/2020	10

Landsat, Sentinel-2 images were collected (Table 1), pre-processed before inputting to the DSAS model. The FLAASH and Sen2cor tools were used in the pre-process procedure for Landsat and Sentinel-a images, respectively, to obtain land surface reflectance data. Both FLAASH and Sen2cor require image acquisition times/dates of image acquisition and atmospheric conditions to remove effects of the atmosphere on the initial images.

2.3. Methods

Figure 2 depicts the main scheme to archive our study goals including four stages of: 1) Data collection and pre-processes. 2) Calculating the Modified Normalized Difference Water Index (MNDWI), determining a threshold for water separation, smoothing initial water line, deleting irrelevant objects, separating the shoreline, building the baselines. 3) Applying the DSAS tool to create cross-sections, calculating the shoreline variations using models in the DSAS. 4) Analyzing and evaluating the results.

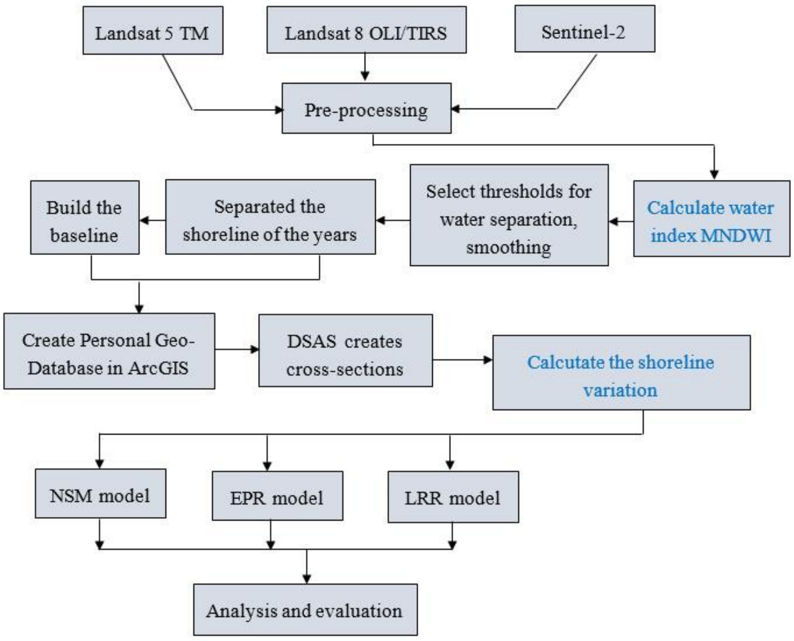

Figure 2. *Workflow of method*

2.3.1. Calculate water index

The water separation was done by using the water threshold calibrated well by [13] based on the MNDWI (equation 1). Therefore, the study will not evaluate the accuracy of the method's ability to extract water surface but focuses on analyzing and evaluating fluctuations in the shoreline of the study area.

$$\text{MNDWI} = \frac{\rho_{green} - \rho_{swir}}{\rho_{green} + \rho_{swir}} \qquad (1)$$

Where the ρ_{green} and ρ_{swir} are the pixel values from the green and short-wave infrared bands, respectively.

2.3.2. Calculating changes of shoreline

Changes in shoreline positions were calculated using three statistical models included in DSAS software containing the End Point. Rate (EPR), Linear Regression Rate (LRR) and Net Shoreline Movement (NSM). The EPR method is a very popular method for calculating coastline variability. The LRR is an user-friendly tool to use compared to current similar tools. The NSM method has abilities to represents the shoreline variations providing basis information for calculating the EPR value.

- ***Net Shoreline Movement (NSM):*** is the distance between the first and the last shorelines for each transect (Figure 3).

- ***End Point Rate (EPR)*** is calculated by dividing the distance of shoreline movement by the time elapsed between the first and the latest shoreline (Figure 3). The major advantages of the

EPR are a computational efficient and minimal data requirement (only two shoreline dates required). The disadvantage is that when more data are available, the additional information is ignored resulting in the tipping changes (from accretion to erosion), magnitude, or cyclical trends may be missed. EPR is calculated by solving the equation 2.

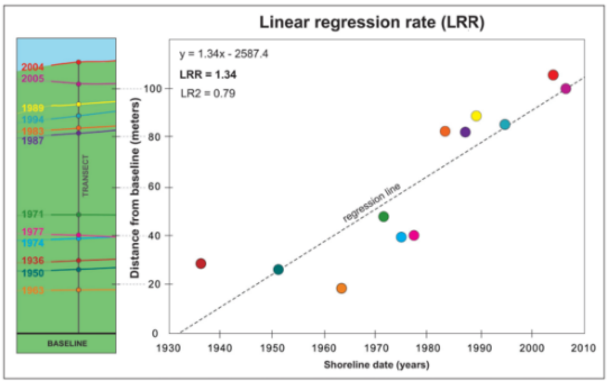

Figure 3. *A shoreline dataset including baseline (black), transect (gray), and shoreline and intersect data (multicolor) to illustrate the relationship between shoreline change statistics: net shoreline movement (NSM), end point rate (EPR), and shoreline change envelope (SCE). (source: Digital Shoreline Analysis System (DSAS) Version 5.0 User Guide of USGS)*

$$EPR = \frac{NSM}{Time\ between\ the\ first\ and\ last\ shorelines} \quad (2)$$

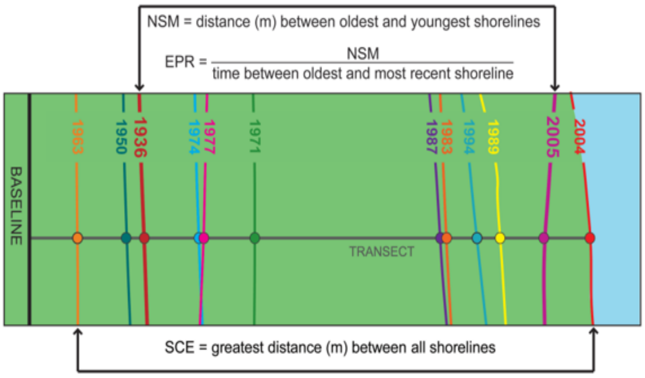

Figure 4. *A shoreline dataset (baseline [black], transect [gray], and shorelines and intersects [multicolor]) to describe the relationship between time and space data on the map, and as presented in a graphical form as distance from the baseline versus the shoreline date. The linear regression rate (LRR) was determined by plotting the shoreline intersect positions (distance from baseline) with respect to time (years) and calculating the linear regression equation of $y = 1.34x - 2587.4$. The slope of the equation describing the line is the rate (1.34 meters per year) (*source: Digital Shoreline Analysis System (DSAS) Version 5.0 User Guide của USGS*)*

Linear Regression Rate (LRR): A linear regression rate-of-change statistic can be determined by fitting a least-squares regression line to all shoreline points for a transect (Figure 4). The regression line is placed so that the sum of the squared residuals (determined by squaring the offset distance of each data point from the regression line and adding the squared residuals together) is minimized. The linear regression rate is the slope of the line. The method of linear regression includes these features: (1) all the data are used, regardless of changes in trend or accuracy, (2) the method is purely computational, (3) the calculation is based on accepted statistical concepts, and (4) the method is easy to employ Dolan et al. (1991) and Crowell et al (1997) stated. However, the linear regression method is susceptible to outlier effects and tends to underestimate the rate of change relative to other statistics, such as EPR [14], [15].

3. Results and Discussion

3.1. Shoreline extraction and smoothing

The water extraction results are shown in Figure 5 with the surface water vectors overlaid with the calculated MNDWI image. The water extraction threshold for the Landsat (5.8) was the water pixel value greater than 0.12 and for the Sentinel-2 was pixel value > 0.4 agreed with findings of [10]. The surface water vector files are smoothed and the extraneous objects removed to get the years shorelines.

Figure 5. *(a) MNDWI index image; (b) Water separation threshold; (c) Shoreline obtained*

3.2. DSAS shoreline demostration

On the basis of the time series shorelines obtained (Figure 6a), a baseline is built (the bold red line in the Figure 6b). The shorelines and baseline are sequently imported into the models in DSAS for the calculation and volatility analysis.

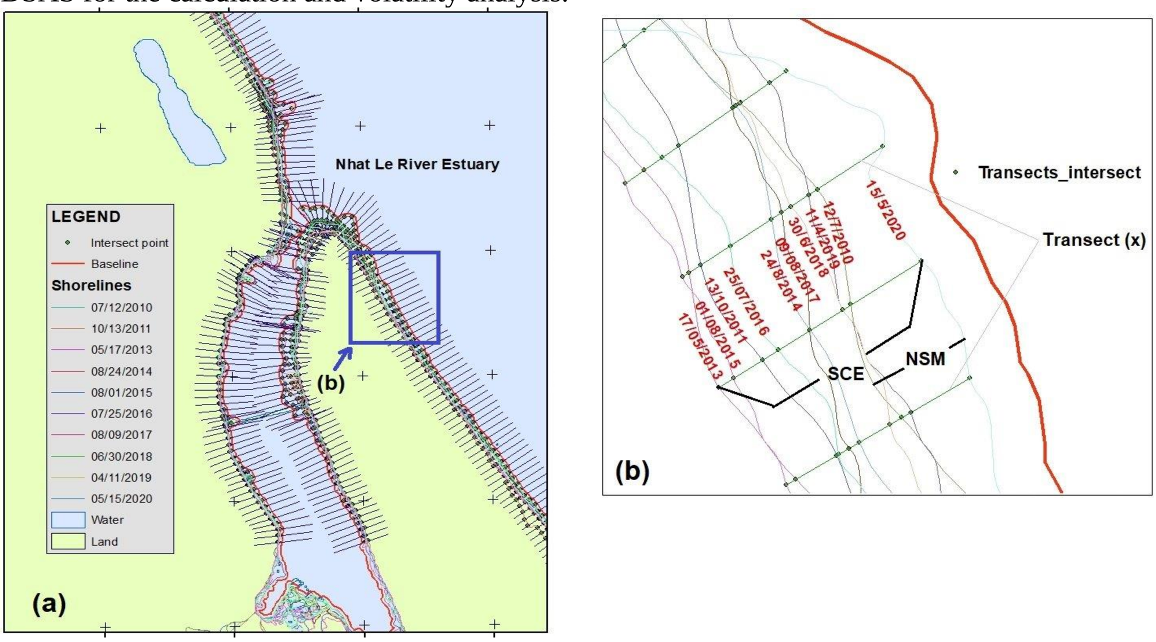

Figure 6. *(a) Obtained shorelines and baselines; (b) shoreline; baseline; The transects are spaced 50m apart, the intersection point are constructed from the DSAS*

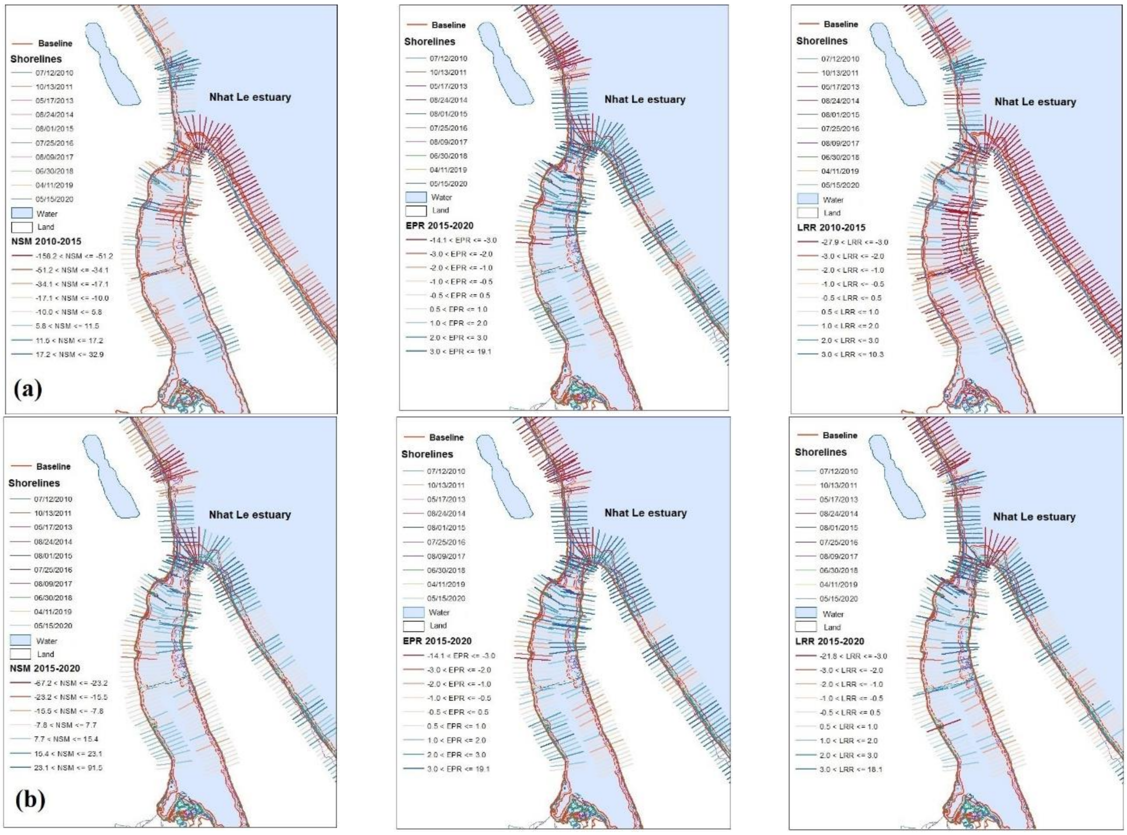

Figure 7. *Analysis and identification of erosion/accretion cuts using NSM, EPR, LRR functionalized in DSAS software integrated in ArcGIS based on shorelines separated from satellite images of periods (a)2010 -2015; (b)2015-2020*

The cross-sections were made orthogonal from the baseline through the shorelines of the different years with the interval of 50 m longitudinal crossings from North to South of the shoreline of the study area. These cuts, which statistically show the shoreline change rate, are automatically calculated by different statistical models (EPR, LRR and NSM). The results classifying into two types: accretion (blue color cut line) and erosion (gamut cut line red, orange) (Figure 7). The delineation of erosion and accretion cuts showed most of the shorelines always fluctuated during the 2010-2020 period. Both erosion and accretion did not vary in a certain trend. However, in the period 2010-2015, the erosion process was more dominant, hence the Nhat Le shoreline was seriously eroded (Figure 7). In the 2015-2020 period, Quang Binh province has invested in building sea embankments along the Nhat Le river. Therefore, It was depicted that the erosion was greatly limited and the sedimentation was somewhat increased, as a result of that, the shoreline changes seemed to be more stable.

3.3. Statistical shoreline changes

Table 2 shows erosive changes in length and rate of the Nhat Le shoreline as results from the NSM model in the period 2010-2015, 75% (196 sections), in the period 2015-2020, 30% (78 sections) and 60% in the whole period from 2010-2020 (157 sections) with a total shoreline length of 16.7 km and 261 transects. On the other hand, 25% (64 segments), 70% (182 segments) and 39% (103 segments) of the shoreline were categorized in accretionary mode (Table 2). The results of this study are summarized and shown in Table 2; represents the average, maximum and minimum rates of shoreline variation as well as the ratio of erosion and accretion cross-sections.

The negative and positive values of EPR, LRR and LMS shown in Table 2 indicate the areas of accretion (above the unchanged line) and erosion (below the unchanged line), respectively.

Table 2. *Statistical table of combined erosion - accretion from NSM, EPR, LRR models*

	2010-2015	**2015-2020**	**2010-2020**
Total number of Transects	**261**	**261**	**261**
Total length of shoreline (m)	**16.700**	**16.700**	**16.700**
NSM_avg accretion (m)	10.20	16.16	14.60
NSM_avg erosion (m)	−29.54	−10.55	−29.21
NSM_max accretion (m)	32.83	91.49	71.12
NSM_max erosion (m)	−158.14	−67.14	−162.00
Average accretion change rate (m/year)			
- EPR	2.02	3.43	1.50
- LRR	2.05	3.02	2.46
Average erosion change rate (m/year)			
- EPR	−5.94	−2.37	−2.97
- LRR	−5.14	−2.12	−2.63
The ratio of the maximum accretion change value (m/year)			
- EPR	6.49	19.10	7.22
- LRR	10.30	18.05	7.48
The ratio of the maximum erosion change value (m/year)			
- EPR	−31.28	−14.02	−16.46
- LRR	−27.89	−21.74	−16.28
Total accretion transects / Percentage (%)			
- NSM	64/25	182/70	103/39
- EPR	64/25	179/69	102/39
- LRR	74/28	161/62	96/37
Total erosion transects / Percentage (%)			
- NSM	196/75	78/30	157/60
- EPR	196/75	76/29	157/60
- LRR	182/70	95/36	164/63

3.4. Shoreline changes in cut-off characteristics

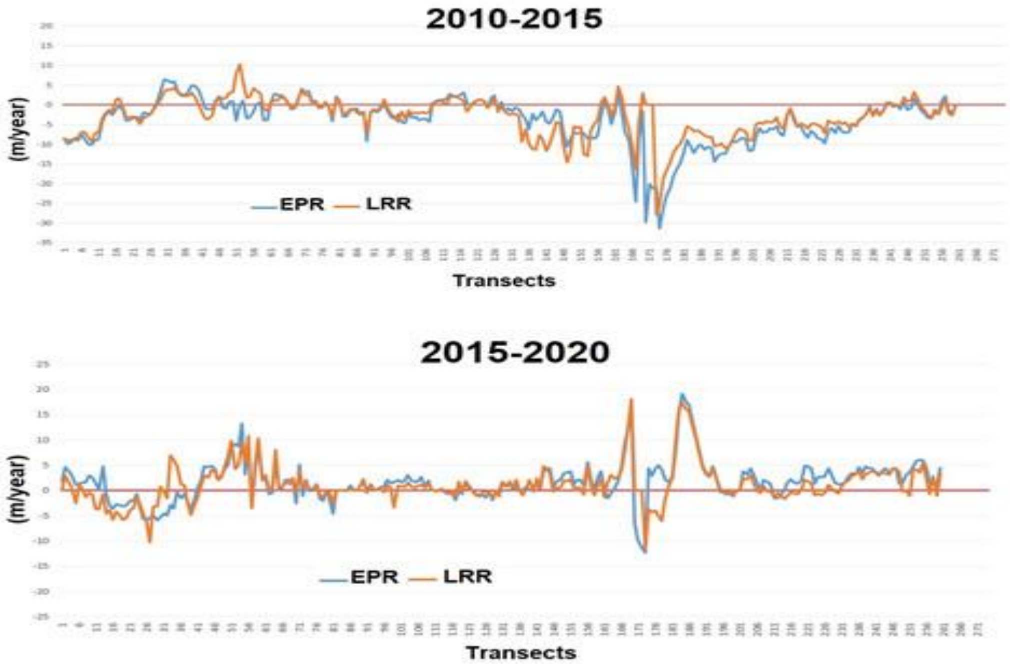

Figure 8. *The shoreline variations (m/year) calculated by EPR, LRR models in the periods of 2010-2015; 2015-2020*

In the 2010-2015 periods, Figure 8 showed various changes in the shoreline along the coast. However, the erosion process was prevail over the deposition, especially from the shoreline from the cut point 161 to the cut point 206 (the mouth of Nhat Le river) was seriously eroded. This was also the case of the east coast of Nhat Le estuary. In the 2015-2020 periods, the shoreline changes seem to be relatively stable where the accretion and erosion took place slightly in some places. The areas of the Nhat riverbanks near by the residential areas mainly had a deposition process, hence seemed to be remarkably stable. The results of NSM, EPR, and LRR are combined with the cutoff characteristics according to the DSAS model results. The red cutline divided the shorelines changes into two categories: accretion above the red cutline with positive rates and erosion below the red cutline with negative rates (Figure 8). The delineation of erosion and accretion cuts showed most of fluctuated lines were on the shorelines during the 2010 to 2020 periods.

4. Conclusion

In the 10-year periods of 2010 – 2020, the shoreline changes of Nhat Le estuary were detected and extracted from the Landsat (5 and 8) and Sentinel-2 images using DSAS software integrated in ArcGIS environment. The study results showed clear shoreline changes of each cutlines revealed abilities of combination of the DSAS and ArcGIS software for coastal studies.

At Nhat Le river estuary, the highest coastal erosion rates were −5.94 (2010-2015), −2.37 (2015-2020) m/year and the highest rates of coastal accretion were 2.05m/year (2010-2015) and +3.43m /year (2015-2020). The rates were considered at medium level compared to other coast lines of Vietnam.

In the study 2010-2015, the changes in Nhat Le shorelines were not in a certain trend but fluctuated in most of the time.

The shoreline seemed to be stable (less erosive and more deposited processes) after the sea embankments along the Nhat Le river was built.

We also found a limitation of spatial resolution of the Landsat (5 and 8) and Sentinel-2 images on the estimated shoreline changing rates. They would be more accurate if we would had images with higher resolutions. However, with the free of charge remote sensing images, this study results certainly could contribute a great support to the coastal management plans and flood mitigations.

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REFERENCES

[1] Nhan Dan, "Solutions to limit erosion of river banks and coasts (translated)," 2021. [Online]. Available: https://nhandan.com.vn/tin-tuc-xa-hoi/giai-phap-han-che-sat-lo-bo-song-bo-bien-635730/. [Accessed Nov. 2021].

[2] A. S. Genz, C. H. Fletcher, R. A. Dunn, L. N. Frazer, and J. J. Rooney, "The predictive accuracy of shoreline change rate methods and alongshore beach variation on Maui, Hawaii," *Journal of Coastal Research*, vol. 23, pp. 87-105, 2007.

[3] K. A. Addo, P. Jayson-Quashigah, and K. Kufogbe, "Quantitative analysis of shoreline change using medium resolution satellite imagery in Keta, Ghana," *Marine Science*, vol. 1, pp. 1-9, 2011.

[4] A. K. Kabuth and A. Kroon, "Wave energy fluxes and multidecadal shoreline changes in two coastal embayments in Denmark," *Ocean Dynamics*, vol. 64, pp. 741-754, 2014.

[5] B. A. El-Sharnouby, K. S. El-Alfy, O. S. Rageh, and M. M. El-Sharabasy, "Coastal changes along Gamasa beach, Egypt," *J Coast Zone Manag*, vol. 17, p. 393, 2015.

[6] T. V. Tran and T. B. Trinh "Shoreline change detection to serve sustainable management of coastal zone in Cuu Long Estuary," in International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Sciences, 2008.

[7] T. V. Tran, T. X. A. Tien, N. H. Phan, F. Dahdouh-Guebas, and N. Koedam, "Application of remote sensing and GIS for detection of long-term mangrove shoreline changes in Mui Ca Mau, Vietnam," *Biogeosciences*, vol. 11, pp. 3781-3795, 2014.

[8] K.T. Bui and C. Nguyen "Analyzing Nha Trang coastline changes of Khanh Hoa province using GIS and remote sensing technique (translated),"Journal of Water Resources & Environmental Engineering vol. 63, pp. 120-127, 2018.

[9] H. Q. Nguyen, "Modelling Soil Erosion, Flash Flood Prediction and Evapotranspiration in Northern Vietnam," Doctoral dissertation, Göttingen, Georg-August Universität, Diss., 2016.

[10] L. C. Torres, A. M. Caravaca, I. F. Reyes, E. O. Chang, M. S. Llull, and L. C. Colina, "An Improvement Method to Study the Spatio—Temporal Dynamics of Rancho Luna Beach´ Shoreline Applying Remote Sensing Tools," in *Proceedings of the 3rd International Conference on BioGeoSciences*, 2022, pp. 69-80.

[11] H. Q. Nguyen, A. T. Vu, T. P. H. Nguyen, T. T. H. Le, M. H. Nguyen, L. A. Vu, *et al.*, "Synthetic aperture radar and optical remote sensing image fusion for flood monitoring in the Vietnam lower Mekong basin: a prototype application for the Vietnam Open Data Cube," *European Journal of Remote Sensing*, vol. 52, pp. 599-612, 2019.

[12] D. C. Dao, Q. M. Nguyen, T. S. Nguyen, V. C. Nguyen " Research on nearshore wave conditions at nhat le coastal area (quang binh province) by using mike21-sw " Journal of Marine Science and Technology; Vol. 18, pp. 241–249, 2018.

[13] A. T. Vu, T. T. H. Le, and H. Q. Nguyen, "Monitoring Urban Surface Water Bodies Changes Using MNDWI Estimated From Pan-sharpened Optical Satellite Images," *FIG Working Week 2019, Hanoi, Vietnam*, 2019.

[14] M. Crowell, B. C. Douglas, and S. P. Leatherman, "On forecasting future US shoreline positions: a test of algorithms," *Journal of Coastal Research*, vol. 13, pp. 1245-1255, 1997.

[15] R. Dolan, M. S. Fenster, and S. J. Holme, "Temporal analysis of shoreline recession and accretion," *Journal of coastal research*, vol. 7, pp. 723-744, 1991.