VIETNAM JOURNAL OF HYDROMETEOROLOGY

Research Article

Riverbank movement of the Mekong River in An Giang and Dong Thap Provinces, Vietnam in the period of 2005–2019

Tran Thi Kim[1,2], Phung Thi My Diem[1], Nguyen Ngoc Trinh[1], Nguyen Ky Phung[3], Nguyen Thi Bay[4,5]*

[1] Ho Chi Minh City University of Natural Resources and Environment; ttkim@hcmunre.edu.vn; ptmdiem@hcmunre.edu.vn; trinhnn@ hcmunre.edu.vn.

[2] Institute for Environment and Resources, Vietnam National University Ho Chi Minh City; ttkim@hcmunre.edu.vn.

[3] Institute for Computational Science and Technology, kyphungng@gmail.com.

[4] Ho Chi Minh City University of Technology; ntbay@hcmut.edu.vn.

[5] Vietnam National University Ho Chi Minh City; ntbay@hcmut.edu.vn.

* Correspondence: ntbay@hcmut.edu.vn; Tel.: +84−8−38654255

Received: 20 October 2020; Accepted: 30 November 2020; Published: 25 December 2020

Abstract: The development of remote sensing and Geographic Information System (GIS) techniques have given a substantial contribution to environmental studies in general and riverbank movement in particular. It helps the monitoring and calculation of the riverbank movement carried out more quickly and effectively. In this study, Alesheikh's method was used to classify the riverbank based on the multi−time Landsat image. The riverbank changes in Tan Chau in the period 2005−2019 were estimated. At the same time, the rate of riverbank change in An Giang and Dong Thap Provinces was calculated in this period by using the Digital Shoreline Analysis System (DSAS), an extension tool of GIS. The results showed that the process of erosion and accretion alternately occurred during the period 2005−2019 and most of the main river branches were eroded. The assessment of riverbank movements using multi−time remote sensing materials contributes a vital role in the management and protection of the shoreline for the socio−economic development planning in the region.

Keywords: Remote sensing; GIS; Landsat image; DSAS; Riverbank.

1. Introduction

Some studies show that erosion has more and more frequently occurred on a large scale along Tien and Hau rivers over the past few decades [1−3]. The average erosion intensity was presented based on the survey in the community living nearby these rivers. The causes, solutions to prevent erosion and to minimize erosion at critical locations have been mentioned by many authors [4−5]. Tan Chau, a town located in the upstream of An Giang province, is so−called a gateway of Tien River flowing into the Mekong Delta of Vietnam. The erosion along the riverbanks and canals happened more and more seriously in the Mekong Delta in general and Tan Chau in particular, causing considerable damage to people, land, houses, property, etc. It is due to the combined influence of natural processes such as river morphology, geological structure, river flow, and the socio−economic activities of the local citizens; for example, sand minion, dam and upstream residential reservoir constructions. Therefore, monitoring the riverbank changes and forecasting its trend in the

Tan Chau play a vital role in the protection and sustainable management of this area riverbank.

In recent years, there have been many studies using remote sensing to classify water surface from multi−time satellite images and to evaluate shoreline movements. Traditionally, medium resolution satellites (e.g., *Landsat and Sentinel−2*) have been used for riverbank studies that did not require very high accuracy [6−8]. NDWI and MNDWI indices for two different types of image sensors were used to study the shoreline movement of the East Coast Nile Delta. The NDWI was calculated as [(Green−NIR)/(Green + NIR)]. The Green and NIR refer to the reflection in the green and near−infrared spectra, respectively. On the other hand, the MNDWI was calculated as [(Green−MIR)/(Green + MIR), where MIR refers to the reflection in the middle infrared band [9−12]. Moreover, in a study of the Bhitarkanika Wildlife Sanctuary in Orissa, the Ration Band method which is using the ratio of image channels between channel 4 and channel 2 to channel 5 and channel 2 was suggested to analyze shoreline movement and sea−level rise along the coast. In particular, the study also indicated that channel 5, the infrared band between the sensor TM and ETM+, showed a strong correlation between water and soil because water absorbs the wavelength of the middle infrared channel (even cloudy water) [13]. Also, the AWEIsh index was used an automatic water extraction for the removal of non−water objects (built−up land) and removal of objects could not be removed [14].

There have been also many studies on shoreline changes carried out in Vietnam in recent years. The remote sensing application and GIS technique (*NDWI index*) were used to analyze the riverbank changes in Phan Thiet area [15]. For shoreline change, the method was applied to assess the erosion and accretion in coastal areas in Ca Mau and Bac Lieu provinces from 1995 to 2010. The pattern of coastline changes of Ca Mau and Bac Lieu was identified using Landsat TM images acquired in 1995, 2000, 2005, and 2010. In the study, a semi−automatic technique to extract the coastline was proposed [16]. Shorelines were also extracted the Da Nang Bay by calculating the ratio of spectral channels for Landsat MSS images based on channel 2 and channel 4, and for Landsat TM and ETM images based on channel 2 and channel 5. All Landsat images for the period from 1972 to 2017 were geometrically converted to UTM coordinate system with a resolution of 30m × 30m and 60m × 60m by using Alesheikh method [17].

Furthermore, many studies used the ratio method to extract the riverbank. Typically, a study in Quang Nam province, the regional riverbank changes of Dai and Thu Bon rivers was calculated. The results showed that the riverbank change was quite suitable, compared to measurement data [18]. Approached the exploitation and processing of multi−time satellite images on the cloud computing platform of Google Earth Engine (*GEE*) in riverbank fluctuation monitoring in the river delta brought about possible results. The study in Mekong Delta established the process of processing, calculating, extracting, and monitoring the riverbank/river bed changes by using Landsat−5, Sentinel−1 image data on the GEE cloud computing platform. The river movement of Tien and Hau rivers in the period of 1988−2018 was evaluated. The results showed the riverbank fluctuation tendency and especially the erosion and accretion speed in the Mekong River region. The results also showed that provinces located in the upstream river such as Dong Thap and An Giang, are more seriously affected by bank failure than the other ones [19], however, they did not consider the diurnal tidal and monsoonal impacts which make difficult to assess sedimentation processes. Also, the erosion and accretion rates were neglect. To deal with it, the results in the period from 1989 to 2014 of Khoi's research showed that the regional and local hydrodynamic characteristic is one of the reasons causing riverbank erosion and accretion. In the river−dominated zone, the erosion and accretion speeds are from medium rates (1–5 m/year) to high rates (> 5 m/year), and erosion processes commonly occur along the Mekong River branch (Tien River) [20].

For a segment flowing through An Giang, Dong Thap, and belongs to Mekong Delta. This section has complex terrain, stream folding, and substantial erosion. The assessment of riverbank change plays a vital role in protecting construction along riverbank [21].

The objective of the study is to assess the riverbank movement of the Mekong River, flowing through An Giang and Dong Thap Provinces in the period 2005 − 2019 by using the multi−time Landsat images and remote sensing image analysis techniques (*Alesheikh's method* [22]) which was evaluated as an effective method to extract riverbank from Landsat U.Duru image data (2017) [23].

2. Materials and Methods

2.1. Materials

The study area is a 24 km long river segment flowing through An Giang and Dong Thap Provinces which belong to Mekong Delta, Vietnam (Figure 1) from Vietnam−Cambodia boundary (X: 10°54'35.07"N, Y: 105°11'23.48"E) to Long Khanh islet downstream (X: 10°46'36.20"N, Y: 105°20'56.96"E). The study segment has braided−river−style. The riverbed has been getting wider, and there are sandbars formed in this area. The terrain of this study area is complex. The river shape is meandering and the river has been strongly eroded.

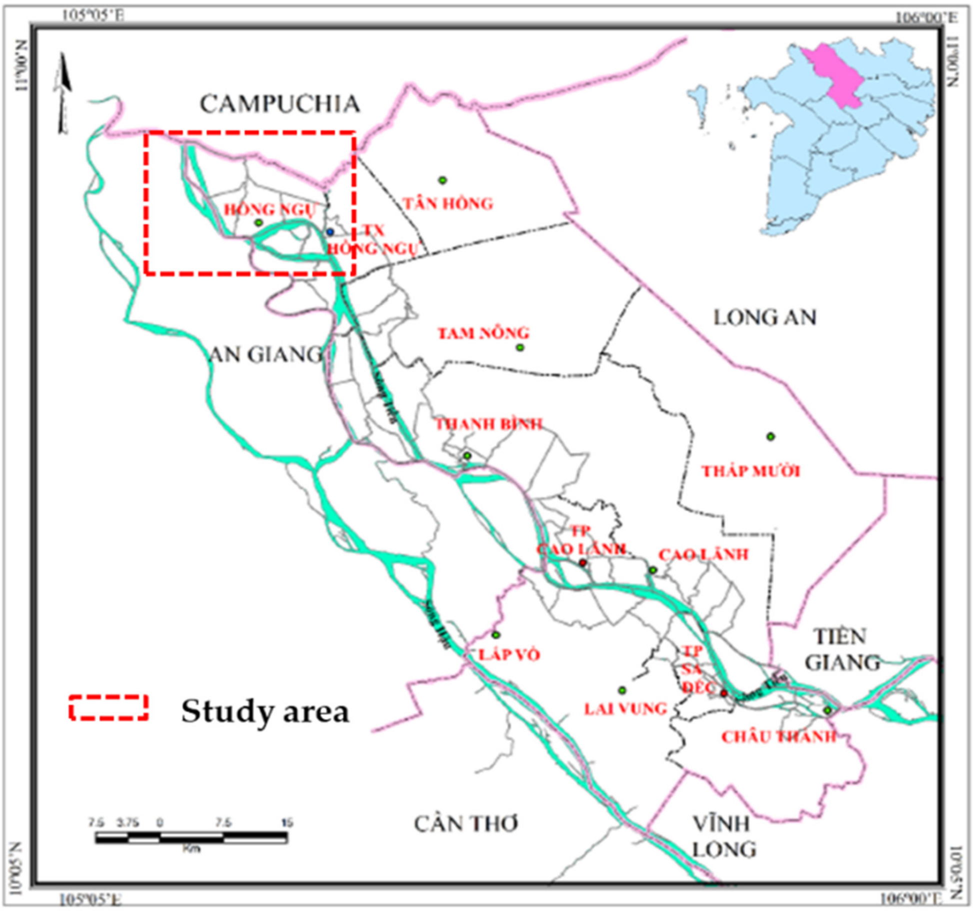

Figure 1. Map of the study area.

Multi−time satellite imagery including Landsat 4−5 (TM) and Landsat 8 Operational Land Imager (*OLI / TIRS*) images of the years 2005, 2010, 2015 and 2019 obtained from the US Geological Survey (*USGS*) (*www glovis.usgs.gov*) were used (Table 1). For the high quality of analysis, the images from July to December with less than 10% cloud coverage of the entire area and without sensor failure (near the riverbank) were selected.

Table 1. Remote sensing image data.

Column/row	Date	Satellite	Resolution	Number of image channels
126/052	19/11/2005	Landsat4−5TM	30m	7
126/052	27/12/2010	Landsat 8 OLI/TIRS	30m	11
126/052	9/12/2015	Landsat 8 OLI/TIRS	30m	11
126/052	28/12/2019	Landsat 8 OLI/TIRS	30m	11

2.2. Methodology

To evaluate the shoreline variation, three steps were carried out: (1) Image preprocessing; (2) Shoreline extraction based on the method of Alesheikh [22] (Figure 3); and (3) Shoreline variation calculation using DSAS (Computer Software for Calculating Shoreline Change).

2.2.1. Image preprocessing

Image geometry correction and atmospheric effects: The geometric and atmospheric corrections were made for the downloaded satellite images. The image coordinate system of these images was adjusted to the same with that of the Tan Chau base map, the UTM 48N projection zone (WGS84).

Merging and cropping: The study area captured by the Landsat satellite is on two separate images. So, it is necessary to crop and stitch the images together to obtain a complete study area image (Figure 2).

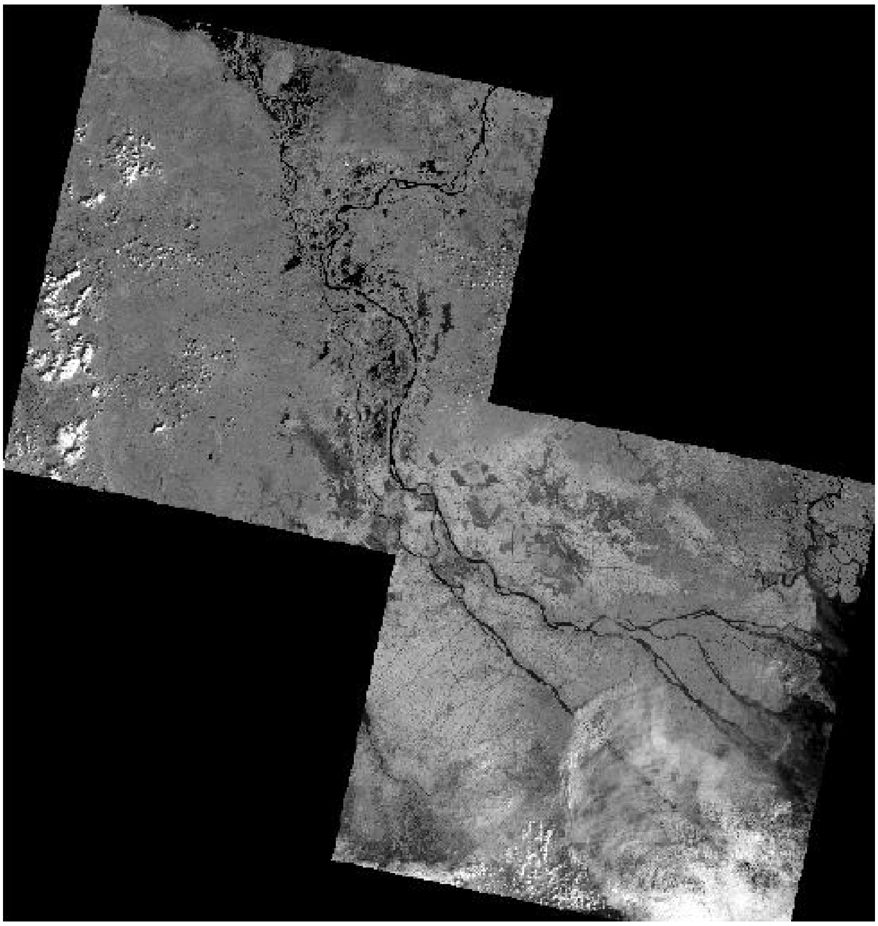

Figure 2. Channel 4 image after merging in 2005.

2.2.2. Shoreline extraction

The image channel ratio and the Filter High methods were used for image filtering to make the maps of shoreline movement. The implementation framework is shown in Figure 3.

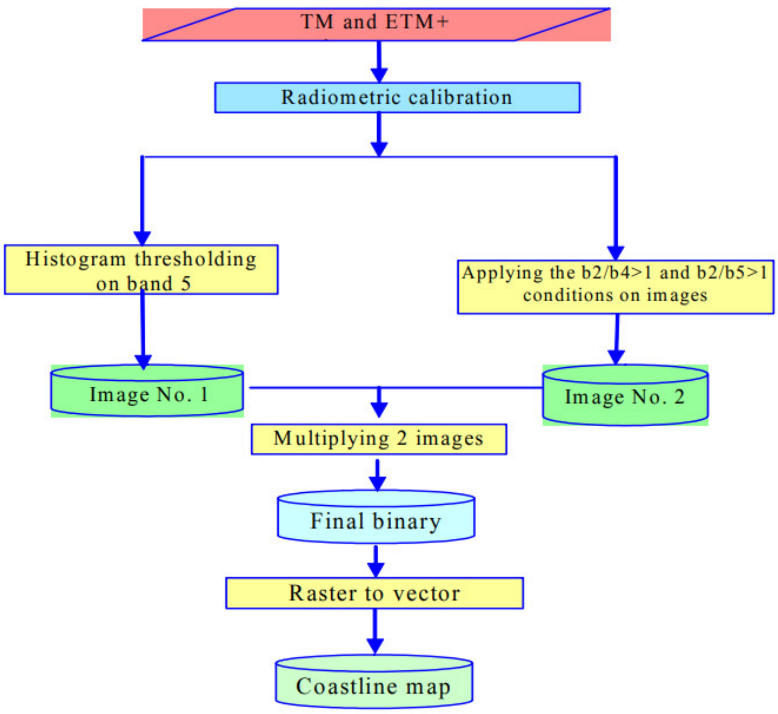

Figure 3. Shoreline separation is based on the method of Alesheikh [22].

2.2.3. Shoreline variation

The DSAS was used to calculate the differences in the shoreline rates, which were extracted from the fuzzy clustering – interactive thresholding method and manually digitized method.

The following statistical measures [24] are possible in DSAS to use [25]:

(i) Shoreline Change Envelope (SCE): The shoreline movement at available shoreline positions and the distances between them are measured and reported.

(ii) Net Shoreline Movement (NSM): The distances between the earliest and the lasted shorelines are reported

(iii) End Point Rate (EPR): It is derived by dividing the distance of shoreline movement by the time elapsed between the earliest and the lasted shoreline positions.

(iv) Linear Regression Rate (LRR): a rate−of−change statistic is determined by fitting a least square regression to all shorelines at specific transects. Further statistics associated with LRR include Standard Error of Linear Regression (LSE), Confidence Interval of Linear Regression (LCI) and RSquared of Linear Regression).

3. Results

The analysis results show that the fluctuation of erosion−accretion has occurred along the riverbank of the segment in the period 2005–2019 (Figures 4−6). Landsat images have a spatial resolution of 30 m × 30 m, so instead of illustrating riverbanks for each year, the remote sensing images once every five years (2005, 2010, 2015, and 2019) are collected in the research. The erosion and accretion area for each period is calculated as Table 2 and Figures 4−6.

Table 2. The erosion−accretion along the river for each period from 2005 to 2019.

Period	Accretion (ha)	Erosion (ha)
2005−2010	328	410.6
2010−2015	270.1	310.1
2015−2019	170	573.5

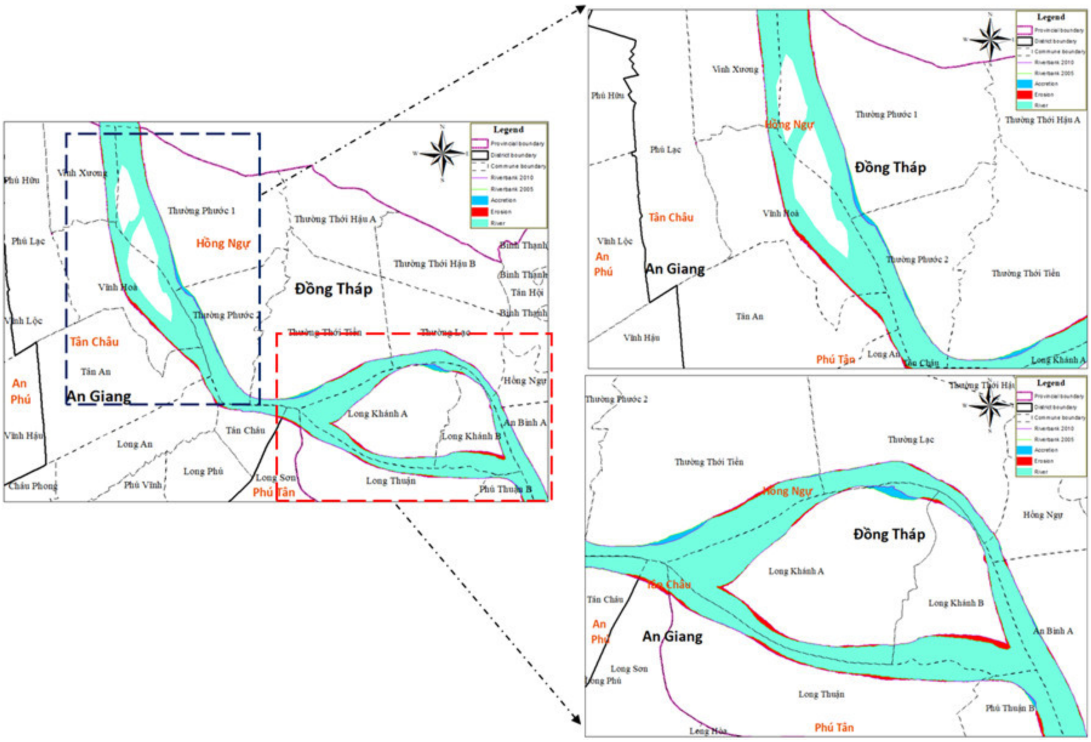

Figure 4. Riverbank erosion−accretion in the period 2005–2010.

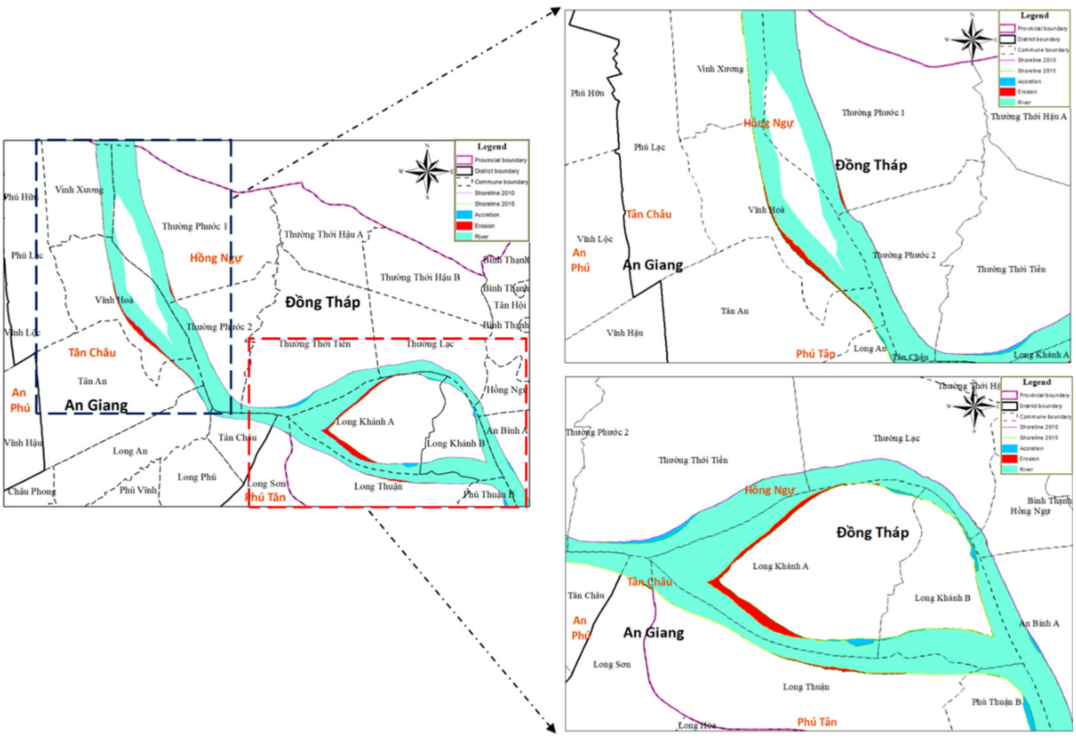

Figure 5. Riverbank erosion−accretion in the period 2010–2015.

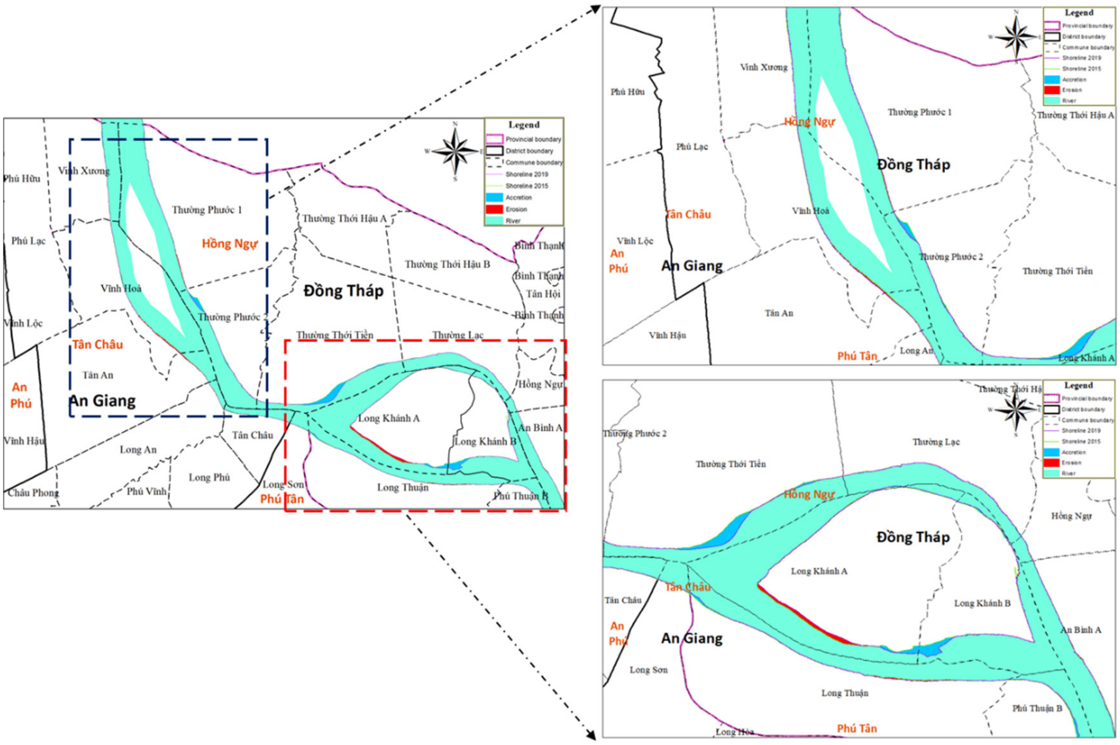

Figure 6. Riverbank erosion−accretion in the period 2015–2019.

From 2005 to 2010

Analytical results present that in the period 2005–2010, the left bank of the river segment from Vinh Hoa to Vinh Xuong Commune (in An Giang) was eroded at the highest rate of 21.56 m/year and Vinh Hoa commune eroded 49.42 ha (Figure 7 and Figure 4). Besides, a slight erosion was recorded in the riverbank in Long Thuan Commune. The measurement results showed that the bottom was more eroded and skewed towards the An Giang Province. During the data collection, we discovered that sand mine made the bed river more eroded [21]. Due to Tan Chau embankment built−in 2003, the riverbank of the segment was quite stable at Tan Chau Commune. In general, erosion was more dominant than accretion in this period in An Giang.

In Dong Thap Province, the Thuong Phuoc 1 and Thuong Phuoc 2 communes (Hong Ngu district) were accreted at medium rates of about from 10.4 to 12.06 m/year. High erosion could be observed not only in this segment but also in the upstream islet of Long Khanh A commune with 12.29 m/year. According to Khoi D.N.'s research, 2020 [20], the most influential erosion mechanism in this area was toe scouring, with the consequent bank failure. In contrast, the accretion was negligible. The rate of change in shoreline in An Giang and Dong Thap Province of the period 2005–2010 is shown in Table 3.

From 2010 to 2015

The analysis shows that the erosion segments mainly occur in Vinh Hoa, Vinh Xuong Commune (An Giang Province) with the highest erosion 25,26 m/year (Table 3). Slight accretion was observed on the riverbank of the Tan Chau embankment (Figure 5). In the period, erosion was still more dominant than accretion in An Giang.

Compared in the period 2005–2010, the erosion rate has shown a slightly decreased temporal tendency in the upstream islet of Long Khanh A commune at 21.3 m/year. Although the erosion area showed notable erosion (highest erosion in Long Khanh A commune), the riverbank of the segments in other commune was quite stable. The rate of change in shoreline in An Giang and Dong Thap Provinces of the period 2010–2015 is shown in Table 3.

From 2015 to 2019

During this period, alluvial sediment was reduced by two−thirds compared to the previous period [26], and, accordingly, the sediment boundary was also reduced. The calculation results show that the whole study area tended to erode. The major erosion segment was approximately 5 km−long and located in Vinh Hoa with an erosion speed of 28,56 m/year.

A higher erosion tendency which is compared in the period 2005–2015 was observed in Thuong Phuoc 2 Commune the upstream islet of Long Khanh A commune at 16.4−29.27 m/year (Table 3). The rate of change in shoreline in An Giang and Dong Thap Provinces of the period 2015–2019 is shown in Table 3.

Table 3. Rate of change in shoreline in An Giang and Dong Thap Provinces of the period 2005–2019.

Province	Commune	2005 – 2010		2010 – 2015		2015 – 2019	
		Accretion rate (m/year)	Erosion rate (m/year)	Accretion rate (m/year)	Erosion rate (m/year)	Accretion rate (m/year)	Erosion rate (m/year)
An Giang	Vinh Hoa	3.45−4.08	4.71−21.56		2.45−25.26	2.15−5.02	2.45−28.56
	Vinh Xuong	0.19−0.28	0.14−2.92		0.28−2.92	0.28−2.92	0.28−2.42
Dong Thap	Hong Ngu	0.32−2.13	0.42−2.16	0.37−1.9	0.42−2.16	0.42−1.93	0.42−2.16
	Long Khanh A	8.03−25.75	12.28−22.96	2.28−19.02	16.4− 21.3	9.38− 19.27	16.4− 29.27
	Long Khanh B	0.09−11.64	3.78 − 12.29	1.98−12.20	3.78− 10.45	3.78− 12.29	2.77− 14.29
	Thuong Phuoc 1	3.2−11.33	0.33−1.27	3.2−11.33	2.31− 2.52	2.98− 3.57	1.93−2.77
	Thuong Phuoc 2	10.4−12.06	7.87−8.43	10.27−11.69	2.37− 3.43	4.04− 10.43	2.37−4.43
	Thuong Thoi Tien	10.24−12.43	6.37−9.1	11.92−12.43	2.16−9.1	2.36−12.26	2.3−9.1

In comparison with the observation data of 12 July 2006 and 21 December 2019 (from the Department of Investment and the Tan Chau Construction Project) (Figure 7), the trend of the riverbank movement was adapted to the actual process. However, the rate of analysis accretion on the left bank of the river segment (Dong Thap) was 0.28 km in the period 2005 – 2019, compared to 0.42 km of observation from 2006 to 2019. This is explained as due to the time of data collection, hence, the change of water level had affected the mudflat area. The limitation of this study was that it focused on analysed the riverbank movement without islet change (Chinh Sach islet as Figure 7).

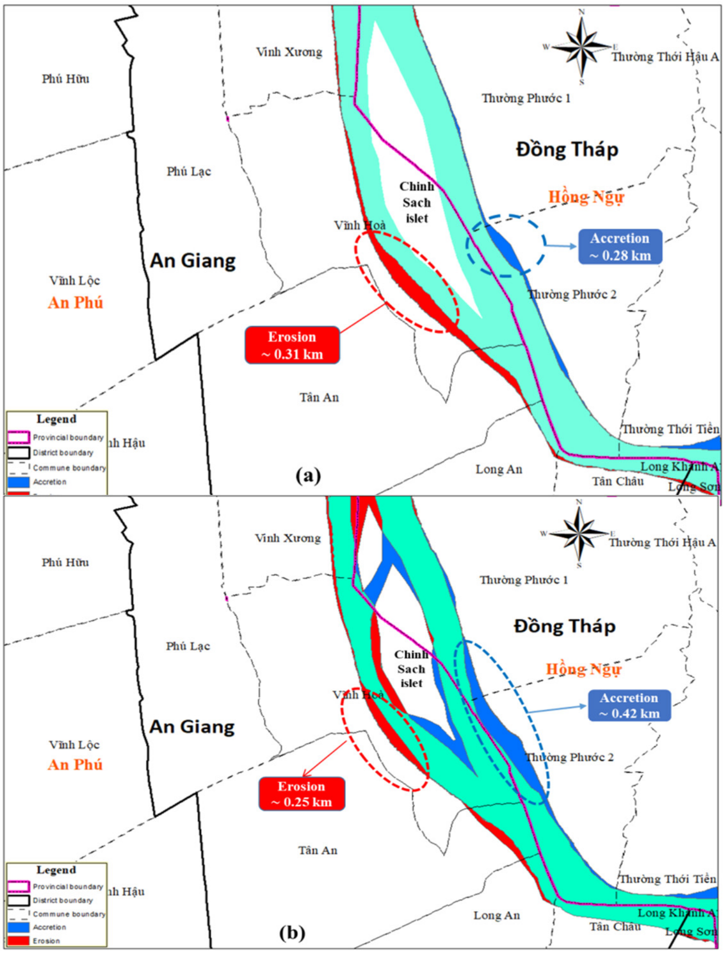

Figure 7. Analysis results in the period 2005–2019 (a) and observations in the period 2006–2019 (b).

4. Conclusions

In summary, the analysis results of riverbank movements in An Giang and Dong Thap Provinces achieved quite good results when compared to measurement data and previous studies [20]. Therefore, the research's method can be applied to a typical large area such as the Mekong Delta, giving optimal results on each main river branch. In this study, Landsat 5 and Landsat 8 remote sensing images were used to evaluate shoreline changes in An Giang and Dong Thap Province of the period 2005–2019, each segment has a different rate of variation.

The analysis results were observed that the erosion was more dominant than accretion in this period for both An Giang and Dong Thap Provinces. In An Giang, the erosion segments mainly occur in Vinh Hoa, Vinh Xuong Commune with the highest erosion of 21.56 m/year from 2005–2010, 25.26 m/year from 2010–2015 and 28.56 m/year from 2015 to 2019. At Tan Chau Commune, due to Tan Chau embankment built−in 2003, the riverbank of the segment was quite stable.

In Dong Thap Province, high erosion was observed not only in the river segments but also in an upstream islet of Long Khanh A commune. The erosion rate of the islet decreased from 2005−2010 to 2010−2015 (22.96 and 21.3, respectively) and then suddenly creased from 2015−2019, and the value has been creased to 29.27 m/year.

Author Contributions: Conceptualization, T.T.K., N.T.B; Methodology, T.T.K., N.K.P., N.T.B.; Software, T.T.K., P.T.M.D; Validation, P.T.M.D.; Formal analysis, T.T.K., P.T.M.D.; Investigation, P.T.M.D.; Resources, T.T.K., N.T.B; Data curation, N.T.B., P.T.M.D.; Writing–original draft preparation, T.T.K., P.T.M.D.; Writing–review and editing, T.T.K., P.T.M.D.; Visualization, T.T.K., P.T.M.D.; Supervision, N.K.P., N.T.B; Project administration, N.K.P.; Funding acquisition, N.K.P.

Funding: This research was funded by the Institute for Computational Science and Technology, with the topic "Development of bank erosion numerical model basing on HPC in connection with hydraulic model and to apply for some river reaches of the Mekong River", (Grant No. NĐT.28.KR/17).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Quynh, H.N.N.; Khoi, D.N.; Hoai, H.C.; Bay, N.T. Application of remote sensing and GIS for riverbank assessment in the BASSAC and Mekong Rivers. *VN J. Hydrometeorol.* **2018**, *08*, 12−22.
2. Hai, H.Q. Correlation of erosion–aggradation in areas along Tien and Hau Rivers. *VN J. Earth Sci.* **2011**, *33*, 37–44.
3. Lam−Dao, N.; Pham−Bach, V.; Nguyen−Thanh, M.; Pham−Thi, M.T.; Hoang−Phi P. Change detection of land use and riverbank in Mekong Delta, Vietnam using time series remotely sensed data. *J. Res. Ecology* **2011**, *2*, 370−374.
4. Li, X.; Liu, J.P.; Saito, Y.; Nguyen, V.L. Recent evolution of the Mekong Delta and the impacts of dams. *Earth Sci. Rev.* **2017**, *175*, 1−17.
5. Hoai, H.C.; Bay, N.T.; Khoi, D.N.; Nga, T.N.Q. Analyzing the causes producing the rapidity of river bank erosion in Mekong Delta. *VN J. Hydrometeorol.* **2019**, *7*, 42–50.
6. Dominici, D.; Zollini, S.; Alicandro, M.; Della Torre, F.; Buscema, P.M.; Baiocchi V. High Resolution Satellite Images for Instantaneous Shoreline Extraction Using New Enhancement Algorithms. *Geosciences* **2019**, *9*, 123.
7. Dominici, D.; Beltrami, G.M.; De Girolamo, P. Ortorettifica di Immagini satellitari ad alta risoluzione finalizzata al monitoraggio costiero a scala regionale. *Stud. Cost.* **2006**, *11*, 145–146.
8. Paravolidakis, V.; Ragia, L.; Moirogiorgou, K.; Zervakis, M. Automatic Coastline Extraction Using Edge Detection and Optimization Procedures. *Geosciences* **2018**, *8*, 407.
9. El−Asmar, H.M.; Hereher, M.E. Change detection of the coastal zone east of the Nile Delta using remote sensing. *Environ. Earth Sci.* **2011**, *162*,769−777.
10. Gao, BC. NDWI−A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sens. Environ.* **1996**, *58*, 257−266.
11. Ouma, Y.O.; Tateishi, R. A water index for rapid mapping of shoreline changes of five East African Rift Valley lakes: an empirical analysis using Landsat TM and ETM+ data. *Int. J. Remote Sens.* **2006**, *27*, 3153−3181.
12. Xu, H. Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. *Int. J. Remote Sens.* **2006**, *27*, 3025−3033.
13. Chand, P.; Acharya, P. Shoreline change and sea level rise along coast of Bhitarkanika wildlife sanctuary, Orissa: An analytical approach of remote sensing and statistical techniques. *Int. J. Geomatics and Geosci.* **2010**, *1*, 436−455.
14. Feyisa, G.L.; Meilby, H.; Fensholt, R.; Proud, S.R. Automated Water Extraction Index: A new technique for surface water mapping using Landsat imagery. *Remote Sens. Environ.* **2014**, *140*, 23−35.
15. Thao, P.T.P.; Duan, H.D.; To, D.V. Application of Remote Sensing and GIS for calculating the coastline changes in Phan Thiet. *VN J. Marine Sci. Technol.* **2014**, *11*, 1–13.

16. Diem, P.K.; Minh, V.Q.; Diep, N.T.H.; Den, D.V. Monitoring the shoreline change in coastal area of Ca Mau and Bac Lieu province from 1995 to 2010 by using remote sensing and GIS. *Can Tho Univ. J. Sci.* **2013**, *26*, 35–43.
17. Trung, N.V.; Khanh, N.V. Shoreline variation monitoring using multi−time Landsat satellite images in Cua Dai, Thu Bon River, Quang Nam. *Min. Sci. Geol. J.* **2016**, *57*, 1−10.
18. Binh, N.Q.; Duong, V.N. Mapping shoreline variation using remote sensing technology, applied to Danang Bay. *J. Sci. Technol.* **2018**, *3*, 1−5.
19. Long, V.H.; Giang, N.V.; Hoanh, T.P.; Hoa, P.V. Applying Google Earth Engine in river bank erosion monitoring – a case study in lower Mekong River. *J. Sci.* **2019**, *16*, 38.
20. Khoi, D.N.; Dang, TD; Pham, L.T.; Loi, P.T.; Thuy, N.T.; Phung, N.K., Bay; N.T. Morphological change assessment from intertidal to river−dominated zones using multiple−satellite imagery: A case study of the Vietnamese Mekong Delta. *Reg. Stud. Marine Sci.* **2020**, *34*, 101087.
21. Kim, T.T.; Huong, N.T.M.; Huy, N.D.Q.; Tai, P.A.; Hong, S.; Quan, T.M.; Bay, N.T.; Jeong, W.K.; Phung, N.K. Assessment of the Impact of Sand Mining on Bottom Morphology in the Mekong River in An Giang Province, Vietnam, Using a Hydro−Morphological Model with GPU Computing, *Water* **2020**, *12*, 2912.
22. Alesheikh, A.A.; Ghorbanali, A.; Nouri, N. Coastline change detection using remote sensing. *Int. J. Environ. Sci. Technol.* **2007**, *4*, 61−66.
23. Duru, U. Shoreline change assessment using multi−temporal satellite images: a case study of Lake Sapanca, NW Turkey. *Environ. Monit. Assess.* **2017**, *189*, 385.
24. Thieler, E.R.; Himmelstoss, E.A.; Zichichi, J.L.; Ergul, A. The Digital Shoreline Analysis System (DSAS) Version 4.0 − An ArcGIS Extension for Calculating Shoreline Change. Open−File Report. *US Geological Survey Report No*. **2008**−1278: http://woodshole.er.usgs.gov/projectpages/dsas/version4/. 2009.
25. Temitope, D.T.; Oyedotun. Shoreline Geometry: DSAS as a Tool for Historical Trend Analysis. *Geomorphological Techniques* **2014**, Chap. 3, Sec. 2.2.
26. Jordan, C.; Tiede, J.; Lojek, O.; Visscher, J.; Apel, H.; Nguyen, H.Q.; Quang, C.N.X. and Schlurmann, T. Sand mining in the Mekong Delta revisited−current scales of local sediment deficits. *Sci. Rep.* **2019**, *9,* 1−14.