Monitoring Coastal Erosion and Deposition in Sam Son City, Vietnam – a Contribution from Remote Sensing Data

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Abstract

Studying the trends in shoreline erosion and accretion is essential for a wide range of investigations conducted by coastal scientists, and coastal managers. Shoreline erosion and accretion occur as a result of both natural and human influences. Some areas along shoreline in Sam Son are eroded and deposed by natural coastal processes and human actions, such as storm, wave, tourism activities. Purpose of this work is to study the erosion and deposition in Sam Son over 33 years (1989–2022). Coastlines were extracted using multi-temporal Landsat images, and the shoreline change rate was determined using Digital Shoreline Analysis Systems (DSAS). The results of this paper inlustrated that the shoreline change in Sam Son undergoes significant and varied fluctuations across different areas. At the Hoi estuary, erosion rates vary from -2.22 m/year to -40.32 m/year. The construction of FLC Sam Son is one of the factors contributing to sedimentation loss in the northern part of Sam Son City, which is situated adjacent to the East Sea and next to the Ma River. Furthermore, the accretion rate has strongly increased, reaching 9.7 m/year in the Do River estuary. The phenomenon of sediment deposition serves as the basic for constructing hotels to cater to tourism in Sam Son.

Keywords: *erosion, deposition, remote sensing, DSAS, Sam Son*

1. Introduction

The coastal region is a crucial component of the Earth's surface, as it undergoes changes over both long and short time span [1]. Both coastal management and engineering design necessitate knowledge of the current shoreline location, its past positions, and its projected future positions [2]. Therefore, there is a pressing need to improve our understanding of the long-term dynamics of coastal change to offer scientific support for decision-making in coastal restoration efforts.

Coastal change is affected by natural and anthropogenic activities [3]. The shoreline is the most basic indicator of changes in the coastal environment, implying erosion, deposition, and subsequent recovery [4]. Assessing coastal erosion and accretion in coastal areas is essential for proposing strategies to address future sea-level rise [5]. The rise in sea levels caused by global warming, combined with coastal erosion, is resulting in the loss of shoreline infrastructure [6].

Coastal erosion, defined as the loss of land adjacent to a body of water, is assessed by monitoring the rate of change or horizontal displacement of a shoreline over time [7]. The erosion caused by wave and current action and the disappearance of mangrove vegetation are both attributable to the long-term impacts of human activities [8], disrupt the balance of dynamic coastal actions in the coastal process, leading to the long-term loss of sediment in the coastal zone and resulting in the destructive process of coastline retreat and beach erosion [9]. Coastal erosion represents a serious issue leading to the damage or loss of residences, hotels, and other coastal infrastructure, as well as the undermining of roads. Additionally, it contributes to the degradation and loss of valuable land and disrupts activities such as fishing, navigation, and recreation [10]. In erosion and deposition studies, there is an ongoing discussion about the degree to which coastal erosion is shaped by natural factors in contrast to anthropogenic distribution, encompassing tourism services and urbanization [11].

In contrast to erosion, the deposition process often involves the accumulation of sediment. Deposition happens when a body of water becomes overloaded with suspended or dissolved substances [12]. The rate of sediment deposition is influenced by wave action, seafloor topography [13], winds [14], and fine or light sediment [12]. Beside, the construction of coastal projects also affects the accumulation. For example, the wave barrier embankment outside the estuary significantly reduces the influx of sediment from the sea, causing sediment deposition [13]. In addition, the coastline is also extended seaward by land reclamation to facilitate the development of tourism and urban areas.

The requirement to define the coastline's position and analyze its changes across space and time is especially critical due to the extensive prolonged human habitation in the coastal region [15]. To address the consequences of coastal erosion in the future, we need to gather appropriate data and choose effective methods to determine the coastline position and evaluate shoreline changes. The shoreline change analysis was conducted to determine the rate of shoreline alteration, utilizing a series of multiple shoreline positions over time [16]. The rate of Shoreline changes are evident through erosion and accretion rates.

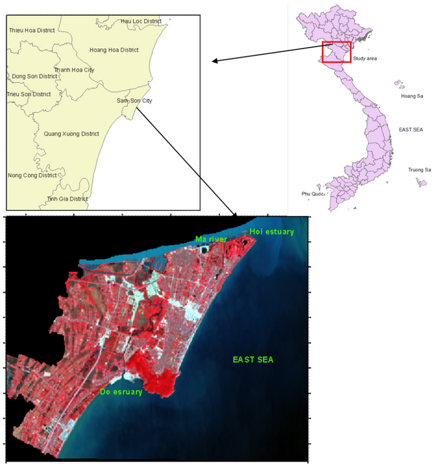

Fig. 1. Study area

Rys. 1. Obszar prowadzonych analiz

Tab. 1. List of satellite data (L8 – Landsat 8; L5 – Landsat 5 TM)

Tab. 1.Dane pozyskiwane z satellitów (L8 – Landsat 8; L5 – Landsat 5 TM)

Type os sensors	Date of acquisition	Bands	Tidal height (m)
L8	2022	2,3,4,5,5,7	3.21
L8	2013.12.27	2,3,4,5,5,7	3.01
L5	2001.09.29	1,2,3,4,5,7	2.81
L5	1989.11.23	1,2,3,4,5,7	2.8

Utilizing geospatial technology demonstrates potential as a valuable asset in delivering comprehensive coverage via multitemporal satellite imagery of coastal regions at diverse resolutions, facilitating the assessment of shoreline changes over time [16]. Various data sources have been utilized for shoreline detection, including historical land-based photographs, aerial photography, coastal maps and charts, GPS field surveys, and remote sensing data [17]. Beside, remote sensing methods for detecting shorelines encompass the extraction of the Green/Near-Infrared ratio [18], applying histogram thresholding to band 5 [19], and NDWI [20]. Recent researches, leveraging the planetary-scale analysis capabilities of Google Earth Engine (GEE), has successfully mapped shoreline change [21]. In addition to using images with average resolution to determine shoreline changes, high resolution satellite images were also used to detect coastal erosion monitoring [22]. Subsequently, aerial photographs and Landsat products were integrated these datasets to determine the magnitude of shoreline fluctuations [23]. In this study, the site-specific rate of erosion and accretion is evaluated using the historical shorelines extracted from the temporal Landsat 5 and Landsat 8 for the period 1989–2022.

Sam Son is the famous coastal city of Thanh Hoa province, is located about 16 km away from the Thanh Hoa city [24]. Despite being favored by tourists, Sam Son tourism also has to face many challenges such as inappropriate resource exploitation, climate change, and rising sea levels. Climate change and rising sea levels have significantly impacted the processes of coastal erosion and sediment deposition. According to research conducted by Cong Quan Nguyen and V.H. Pham (2016), The northern and southern coasts of the Hoi River estuary experience an accretion rate ranging from 5 to 10 meters per year, whereas erosion at the mouth of the Hoi River occurs at a slower rate of approximately 3-5 meters per year [25]. The reduction in width caused by coastal erosion in Sam Son has directly affected livelihoods, infrastructure, tourism attractions, cultural and historical landmarks, seasonality, and all tourism-related activities in the region [24].

This paper aims to evaluate the extent of coastal erosion and sediment deposition along the Sam Son beaches over a span of 33 years (1989–2022) through the analysis of remote sensing data. Coastal erosion and deposition are indicators of shoreline dynamics. The alterations of coastlines were identified through the analysis of NDWI of Landsat images. Furthermore, the Digital Shoreline Analysis System (DSAS) was utilized to calculate the rates of coastal deposition and erosion [26]. The erosion and deposition change were illustrated the results based on five statistical variables: Net Shoreline Movement (NSM), End Point Rate (EPR), and Linear Regression Rate (LRR).

2. Study area

The Coastal Sam Son City is located in Thanh Hoa province, which is famous for its picturesque beaches, drawing a large number of tourists from Vietnam and abroad. The landscape of Sam Son is distinctly divided into four zones: the tidal saltwater zone, the high sandbar zone, the coastal zone, and the mountainous zone. The territory of Sam Son consists of two parts: mainland and sea. This is an advantage for Sam Son to develop its maritime economy, aiming to become a strong coastal city in the near future. However, Sam Son faces challenges related to natural disasters such as flooding, climate change, rising sea levels, and shoreline change.

The coastline of Sam Son stretches approximately 26 kilometers from Quang Tho Ward, along the Ma River and the sea, to Quang Dai Commune. In recent years, the coastline of Sam Son City has experienced notable changes, influenced by both factors of natural origin and anthropogenic. Human activities such as building hydroelectric dams and sand mining contribute to coastal erosion and sedimentation. In addition,

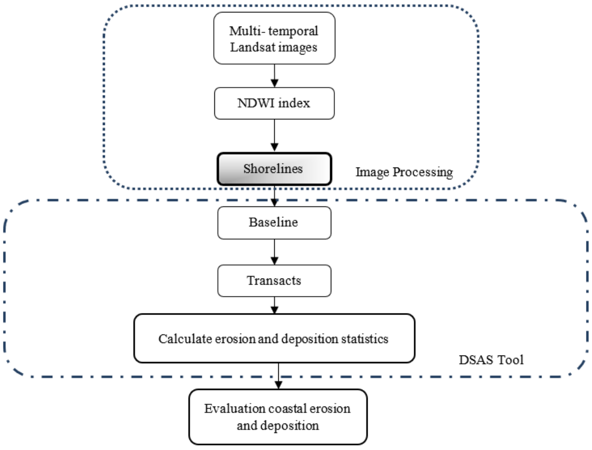

Fig. 2. Flowchart of the overall methodology for assessing coastal erosion and deposition
Rys. 2. Schemat blokowy ogólnej metodologii oceny erozji i osadzania się wybrzeża

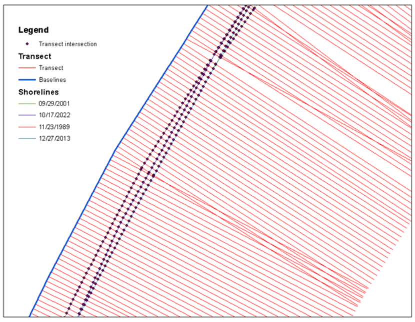

Fig. 3. Initiating transects from the baseline in parallel to the coastline vectors
Rys. 3 . Inicjacja transektów od linii bazowej równolegle do wektorów linii brzegowej

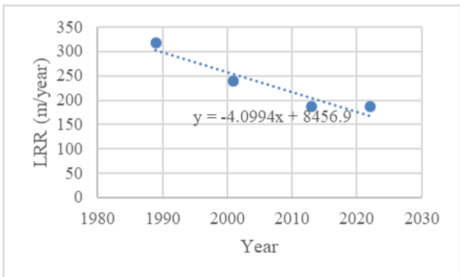

Fig. 4. Representation of a typical cross-plot showing LRR for shoreline change
Rys. 4. Reprezentacja typowego wykresu krzyżowego przedstawiającego LRR dla zmiany linii brzegowej

natural factors such as climate change and rising sea levels also lead to coastal erosion and sedimentation. The diminishing beach area and alterations to the shoreline can profoundly affect tourism activities of Sam Son City, considering the beaches are a primary draw for tourists. Moreover, coastal erosion poses a threat to coastal infrastructure, leading to economic losses.

In conclusion, the complexity of coastline change in Sam Sơn City demands a multifaceted approach for effective resolution. Continuously monitoring the shoreline and implementing suitable measures are essential to guarantee the long-term sustainability of both the coastal environment and the economic development in Sam Son.

3. Methodology and data

We obtained historical multi- temporal Landsat images by downloading it from the United States Geological Survey (USGS) earth explore website for the years 1989, 2001, 2013, and 2022. Landsat-8 OLI and Landsat 5 TM images are with the Word Geodetic System (WGS84) datum and projected using the Universal Transverse Mercator (UTM) System, specifically in zone 48N. The detailed parameters of those images are presented in Table 1.

The detailed methodology and objectives of the whole study is presented in Figure. 2. First, shorelines were extracted from Landsat in 1989, 2001, 2013 and 2022 using NDWI. The NDWI indexes were manually digitized the water – land boundary. The manual digitizing method is seen as the most straightforward technique for shoreline detection when dealing with study sites that are not extensive [27] like Sam Son city. The Digital Shoreline Analysis System (DSAS) tool was utilized to analyze the multi-date shorelines and compute statistics regarding shoreline change.

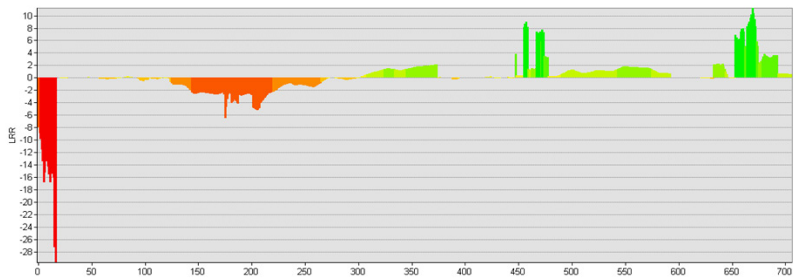

Fig. 5. Coastal accretion and erosion of Sam Son coast with LRR

Rys. 5. Akrecja przybrzeżna i erozja wybrzeża Sam Son z LRR

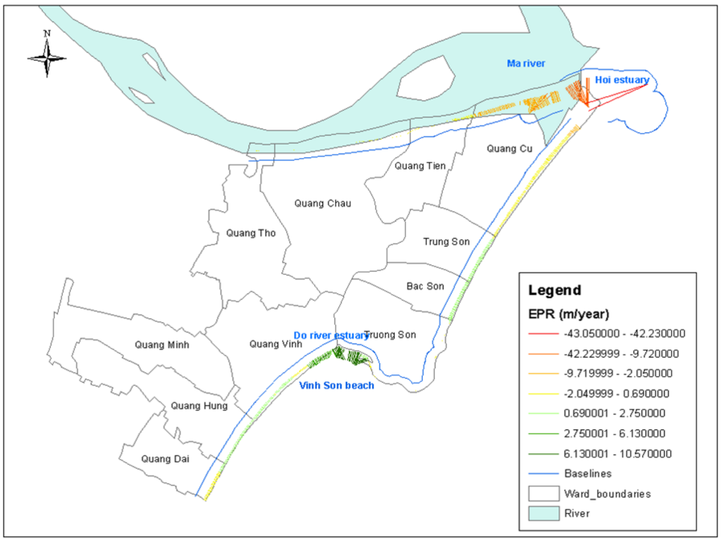

Fig. 6. Coastal accretion and erosion of Sam Son coast with EPR.

Rys. 6. Akrecja przybrzeżna i erozja wybrzeża Sam Son z EPR

3.1. Shoreline Determination

The process of coastline detection using satellite data involves the separation of land and water bodies [28]. There are several water indexes such as Normalized Difference Water Index (NDWI) [29], Automated Water Extraction Index (AWEI) [30], and Modification of normalised difference water index (MNDWI) [31]. In which, the normalized difference water index (NDWI) is a sensitive indicator to alters in body of water and it can be utilized for detecting aquatic entities. It is generated from the near-infrared and short-wave infrared bands of satellite images [32]. The normalized difference water index (NDWI) can be calculated from both the near-infrared and green bands of remote sensing data [29]. One of the most commonly used water indices for coastline extraction is the normalized difference water index (NDWI) [33]. In this paper, the NDWI values were calculated using the formula provided by Gao (1996) in Equation (1).

$$NDWI = (NIR-SWIR) / (NIR+SWIR) \quad (1)$$

Where: NIR is band 4 of Landsat 5 and band 5 of Landsat 8; SWIR is band 5 of Landsat 5 and band 6 of Landsat 8.

The NDWI is utilized for extracting coastlines by method of visual interpretation in shapefile format using QGIS. Therefore, There are four coastlines corresponding to the years 1989, 2001, 2013, and 2022.

3.2. Coastal erosion and deposition detection

Coastal erosion and accretion are determined by assessing the rate of shoreline change. The DSAS tool was utilized in this study to assess shoreline change. The alterations in the shoreline were evaluated by integrating the positions of the shoreline referenced to the established baseline. The changes in the coastline were established by analyzing the intersections of transects oriented perpendicular to the shoreline [20]. In addition

It is essential to establish the baseline next to the series of shoreline positions. Transects should be deployed perpendicular to this baseline at a spacing determined by the user to intersect the shorelines and establish measurement points. The orientation of the transect through the shorelines is significantly influenced by the position of the baseline. In this paper, 854 transverse transects, each 1700 meters long and positioned perpendicular to the offshore baseline, were created at 30-meter intervals along the shoreline (Figure. 3).

The DSAS modul was employed to assess the erosion and deposition rates of shoreline positions using the end point rate (EPR), rate of shoreline change(RSC) and linear regression (LRR) techniques. EPR was calculated as the ratio of the time elapsed between the oldest and most recent coastline positions. Beside, The calculation of the rate of shoreline change in the LRR method is based on the assumption of a linear trend between the earliest and latest shoreline dates (Figure. 4).

In addition, The coastal erosion and deposition changes were analysed respectively in period 1989–2001; 2001–2013,

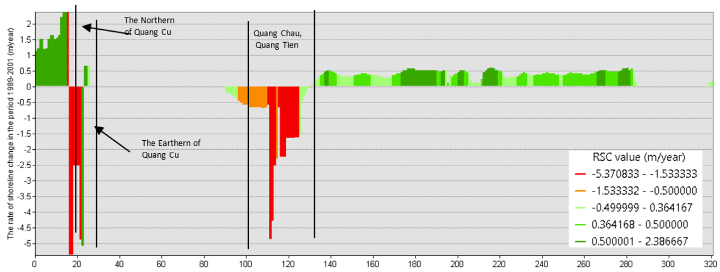

Fig. 7. The rate of erosion and deposition in the period 1989–2001 in Sam Son
Rys. 7. Tempo erozji i osadzania się w latach 1989–2001 w Sam Son

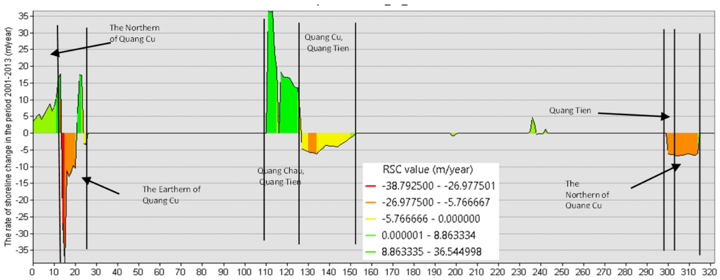

Fig. 8. The rate of erosion and deposition in the period 2001–2013 in Sam Son
Rys. 8. Tempo erozji i osadzania się w latach 2001–2013 w Sam Son

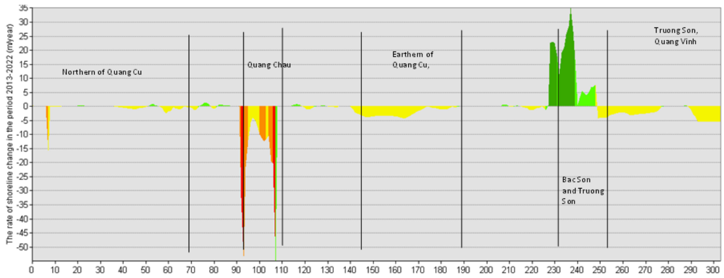

Fig. 9. The rate of erosion and deposition in the period 2013–2022 in Sam Son
Rys. 9. Tempo erozji i osadzania się w latach 2013–2022 w Sam Son

and 2013–2022 by rate of shoreline change(RSC) in following equation (2):

$$RSC = NSM / \text{time between oldest and most recent shoreline} \quad (2)$$

Where NSM (Net Shoreline Movement) is distance between oldest and most recent coastline

The RSC indicates nagative values of the coastal depositon, while positive values of coastal erosion.

4. Results and discussion

4.1 Overall coastal erosion and deposition state

The identification of beach conditions, particularly coastal erosion, relies significantly on the geomorphological attributes of the coastline. The coastline is a dynamic system that undergoes rapid and continuous evolution, and its trends are monitored by mapping at different time intervals through field data collection or satellite imaging [34]. Coastal erosion and accretion are indicators of shoreline changes. The LRR method has been utilized to analyze the rate of shoreline change for Sam Son. According to the study, Sam Son exhibited both erosion and deposition along its coastline. The rate of 854 transects, erosion rates ranged from -0.12 m/year to -29.74 m/year, whereas the deposition rate along the coast ranged from 0.47 m/year to 11.22 m/year (Figure. 5)

Moreover, The end point rate (EPR) is calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline. The EPR suggests that stable and negligible coastal deposition distances are concentrated in Bac Son, Trung Son, Quang Vinh, Quang Hung, and Quang Dai regions (Figure. 6). However, the EPR shows that significant coastal deposition distance are contributed in Quang Cu and Truong Son communes where the EPR reached from 0.69 m/year to 10.57 m/year. In addition, coastal in Quang Cu region is erosed strongly with EPR reached - 43.05 m/year.

The Figure. 7 shows the change of erosion and deposion from 1989 to 2001. The RSC vary between –5.37m/year and 2.39m/year. The coastal deposition was focused in the northern of Quang Cu ward from 0.5m/year to 2.39m/year and accretion is insignificant in Trung Son, Bac Son, Truong Son and Quang Vinh wards (below 0.5m/year). However, the shoreline was erosed from –5.37m/year to – 0.5m/year that was distributed in the Earthern of Quang Cu, Quang Chau and Quang Tien wards.

The change of erosion and deposition from 2001 to 2013 was shown in Figure. 8. Compared to the period from 1989

Tab. 2. Factors influencing coastal tourism in Sam Son (Source: Nguyen and Tran, 2020)
Tab. 2. Czynniki wpływające na turystykę przybrzeżną w Sam Son

Areas	Touristm activities	Limitations
Along the coast of Ho Xuan Huong	Hotels, Public swimming beaches, Shopping, Restaurant	Infrastructure has not fully invested, Sea level rise, Planning is not synchronized
Quang Cu commune		Natural disaster risks; erosion; Environmental pollution; Infrastructure is low; Services are not yet developed; Landslide

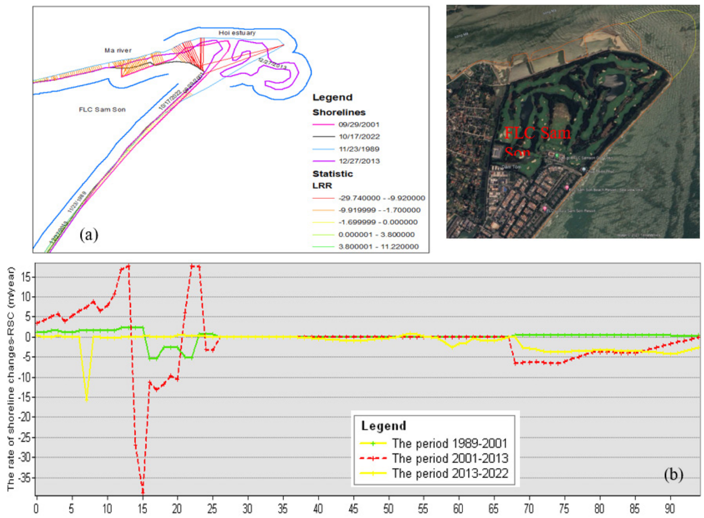

Fig. 10. The rate of shoreline change in Hoi estuary (LRR)
Rys. 10. Tempo zmian linii brzegowej w ujściu rzeki Hoi (LRR)

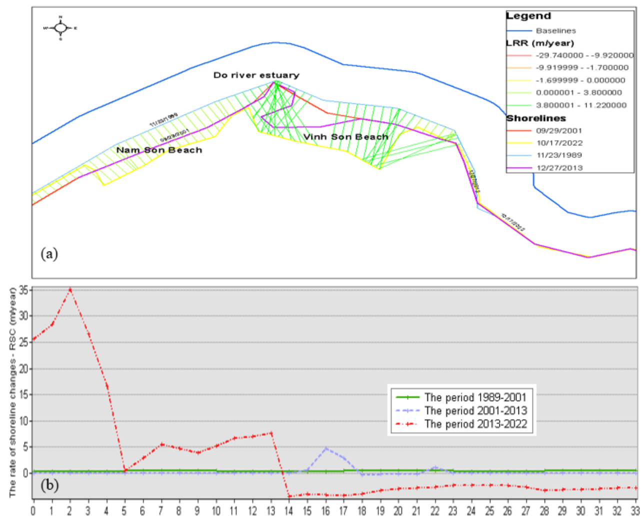

Fig. 11. The rate of shoreline change in Do river estuary
Rys.11. Tempo zmian linii brzegowej u ujścia rzeki Do

to 2001, the shoreline change in the period 2001–2013 was increased rate strongly which ranged from -38.79 m/year to 36.54/year.

In the Quang Cu ward where is located adjacent to the East Sea and next to Ma river in the Northern. In the Northern of Quang Cu ward, the shoreline was occurred both erosion and deposition which was the same phenomenon in the period of 1989–2001. However, the rate of erosion and deposion in the period of 2001–2013 were higher one of the period of 2001–2013. The value of erosion rate varied from -6.0 m/year to -6.67m/year, while the deposition rate value ranged from 4.22 m/year to 17.7 m/year. Beside, the rate of shoreline changes in the Earthern of Quang Cu ward were also different between the period 1989–2001 and the period 2001–2013. In there, shoreline was deposited about 0,6 m/year in the period 1989–2001 and 17.36 m/year in the period 2001–2013, whereas one was eroded significantly to -38.79 m/year in the period 2001–2013. In the Quang Chau and Quang Tien ward, the shoreline was deposed strongly from 6.5 m/year to 36.5 m/year. In addition, Quang Tien ward where was next to Quang Cu was erosed about -6.67m/year.

In the period 2013–2022, the shoreline change in Sam Son city was popular erosion (Figure. 9). The rate of erosion was largest in Quang Chau ward reaching – 55 m/year approximately. On the contrary general erosion trend, Bac Son and Truong Son were deposed strongly from 5 m/year to 35.1 m/year.

5. Discussion

Analysis of the results of the shoreline changes method, which we may regard as the reference method, reveals that the Sam Son coastline has experienced both erosion and deposition between 1989 and 2022. However, coastal erosion and deposition were different on each regions in period 1989–2001, 2001–2013, and 2013–2022 respectively. Overall, the rate of coastal erosion and deposition of Sam Son were most notably characterized by the rate of shoreline changes in Hoi estuary (Figure. 10) and Do river estuary (Figure. 11). In this section, we used LRR to analysis general the rate of erosion and deposition in during 1989–2022. Beside, we also applied RSC to evaluate particularly about the rate of erosion and deposition in each period 1989–2001, 2001–2013, and 2013–2022.

Figure. 10(a) shows LRR ranged from -1.7 to – 29.74. the LRR values proved that the shoreline was erosed in during period 1989–2022. However, as depicted in RSC in Figure. 10(b), the deposition process is specifically concentrated in the southern part of the Hoi estuary, with rates reaching 17.69 meters per year during the period 2001–2013. This accretion rate is the result of the transportation of sediment by the Ma River. The Hoi estuary is situated in the downstream area of the Ma River system, annually releasing millions (around 5.17 million) of tons of sediment into the sea. [35]. Contrastingly, the northern region of the Hoi estuary witnessed substantial erosion, characterized by erosion rates of -4.2m/year in period 1989–2001, -38.79 m/year, and -6.67 m/year in period 2013–2022. In this region, coastal erosion is attributed to a combination of natural elements and activities related to land exploitation. Natural elements comprise climatic events like storms, waves and increasing sea levels [36, 37]. Land exploitation activities contribute to coastal erosion, including urban development, sand mining, infrastructure construction. One of the notable land exploitation activities involves the establishment of tourism accommodation facilities, such as the Sam Son FLC complex and Van Chai resort. Consequently, sand mining in this tourist area has depleted the sediment deposition source, and this activity also generates a turbulent wave current that washes away the sediment, resulting in coastal erosion.

Furthermore, after consulting with stakeholders in the field, it has been recognized that the significant implications of analysis outcomes have impacted infrastructure of tourism [24], such as coastal erosion. The impacts of coastal erosion on marine tourism services in Sam Son are presented in Table 2:

The Do river mouth, situated to the west of the Truong Le mountain range, is the site where sedimentation and the formation of Vinh Son Beach and Nam Sam Son Beach occur. As a result of wave and tide action, sediment and sand get deposited, leading to an accumulation rate of up to 11.22 m/year (Figure. 11(a)) in during 1989–2022. In the region of Do river estuary, deposition processes was dominated with RSC value reaching 35.1 in period 2013–2022 (Figure. 11(b)). The sediment deposition at the mouth of the Do River provides the foundation feature for the development of resort areas aimed at catering to tourism. Currently, this area has undergone sand filling and the establishment of boundaries to facilitate the construction of resorts and hotels.

6. Conclusion

This study has utilized freely distributed multi-temporal Landsat satellite data and image processing techniques to demonstrate that Sam Son city has experienced extensive erosion and deposition between 1989 and 2022. In general, deposition is more significant in the most part of Do River estuary. However, erosion has been remarkable around the area of Hoi estuary. Erosion and deposition of shoreline in Sam Son are closely related to tourism activities. Therefore, addressing the issue of coastline changes in Sam Son City is essential to ensuring the sustainability of the local economy and the long-term attractiveness of the region as a preferred tourist destination.

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Conflicts of Interest

The authors declare no conflict of interest.

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Monitorowanie erozji i osadzania się na wybrzeżu w mieście Sam Son, Wietnam – wkład danych z teledetekcji

Badanie trendów erozji i akrecji linii brzegowej jest istotne dla szerokiego zakresu badań prowadzonych przez naukowców nadmorskich i menedżerów wybrzeża. Erozja i akrecja linii brzegowej występują zarówno w wyniku procesów naturalnych, jak i wpływu człowieka. Pewne obszary wzdłuż linii brzegowej w Sam Son ulegają erozji i akrecji w wyniku naturalnych procesów przybrzeżnych i działań ludzkich, takich jak burze, fale, działalność turystyczna... Celem tej pracy jest zbadanie erozji i akrecji w Sam Son na przestrzeni 33 lat (1989–2022). Linie brzegowe zostały wyodrębnione z wykorzystaniem wieloczasowych obrazów satelitarnych Landsat, a wskaźnik zmian linii brzegowej został określony przy użyciu systemów cyfrowej analizy linii brzegowej (DSAS). Wyniki tej pracy ilustrują, że zmiany linii brzegowej w Sam Son podlegają znacznym i zróżnicowanym fluktuacjom w różnych obszarach. W ujściu rzeki Hoi wskaźniki erozji wahają się od -2,22 m/rok do -40,32 m/rok. Budowa FLC Sam Son jest jednym z czynników przyczyniających się do utraty osadów w północnej części miasta Sam Son, która sąsiaduje z Morzem Wschodnim i rzeką Ma. Ponadto, wskaźnik akrecji znacząco wzrósł, osiągając 9,7 m/rok w ujściu rzeki Do. Zjawisko osadzania się osadów służy jako podstawa do budowy hoteli obsługujących turystykę w Sam Son.

Słowa kluczowe: *erozja, osadzanie się, teledetekcja, DSAS, Sam Son*