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The erosion and accretion at Day River mouth, Vietnam

Ban To Xuan*

*Hanoi University of Mining and Geology

*Corresponding author: Ban To Xuan (toxuanban@humg.edu.vn)

ABSTRACT

The Day River serves as the boundary between Ninh Binh and Nam Dinh provinces in Vietnam. At the mouth of the Day River, the Ninh Binh side features the Kim Son alluvial area, while the Nam Dinh side borders the Nghia Hung coastline. The Kim Son and Nghia Hung areas are key parts of the interprovincial wetland zone of the Red River Delta, which is recognized as a world biosphere reserve. In recent years, the coastal alluvial area of Kim Son has been recorded as the fastest accreting region in the Red River Delta, with an accretion rate of 100–120 meters per year. Studying the processes of accretion and erosion in Vietnam's coastal zones in general, and the Day River mouth in particular, is essential. On the basis of field survey, the analysis of topographic maps, satellite images since 1965, and GIS remote sensing GIS, the changes in the rivershape, erosion, and accretion processes in the Day River estuary have been assessed. Over time, the processes of accretion and erosion occur alternately in both the Kim Son alluvial plain (west of the Day estuary) and the Nghia Hung alluvial plain (east of the Day estuary). Forecasting the trend until 2050, the alluvial plain in the Day estuary will continue to develop the process of accretion and erosion, with accretion being the dominant process, gradually expanding the land area seaward.

Keywords: *Erosion, Accretion, Day River Mouth, Vietnam*

1. Introduction

The Day River flows through Kim Son District, Ninh Binh Province. It serves as the boundary between Ninh Binh and Nam Dinh provinces in Vietnam. The Kim Son area forms an important part of the interprovincial Red River Delta Wetland Biosphere Reserve. Over the years, the coastal alluvial zone of Kim Son has been recorded as having the fastest accretion rate in the Red River Delta region, with an accretion speed of 100-120 meters per year (Pham Thi Nhung, 2017)

In the Day River mouth area, the flow regime is a combination of tidal currents, wind-driven currents, and river flow (from the Day River). Generally, the nearshore current is stable and flows in a northeast–southwest direction. However, observations by many researchers have shown that as the current approaches the Day estuary, its direction shifts to north–south due to the influence of the Day River's flow. This factor partly limits the interaction of materials transported by waves and river currents to the area, resulting in surface sediment formations in the study area being predominantly of fluvial origin rather than marine origin (Pham Thi Nhung, 2017).

The hydrodynamic interaction between river flow and longshore current is a key factor influencing the sedimentation process. The discharge from the Day River into the coastal area is approximately 195,000 m³ per year. In addition, the total annual combined flow across the cross-section at the shoreline of the Nghia Hung area (Nam Dinh Province) moves from north

to south, with a discharge of about 1,807,000 m³ per year. Sediment in the Day estuary is supplied from two major sources: the first is from the Day River, contributing about 34,000 tons of sediment per year, and the second is the longshore current transporting sediment from the north, contributing approximately 220,000 tons of sediment annually (Nguyen Xuan Hien et al., 2012).

The Red River estuary is undergoing accretion, forming mangrove forests and estuarine sandbars, whereas the coast from Giao Hai to the Day River estuary has experienced severe erosion at rates of 5 to 7 m/year over recent decades (Hoang Van Long, 2015).

Nguyen Van Cu (2006) reported that each year approximately 30 million tons of sediment and 32 m³ of water are discharged into the sea through the Day estuary. During the rainy season, this sediment can be dispersed up to 12 km offshore. The longshore sediment transport is influenced by oceanographic factors, while man-made dike systems have a significant impact on the natural shoreline and the development trends of accretion zones. The west-southwestward deflection of the Day estuary flow is related to the dominant northeast–southwest sediment transport direction and the formation of the "Mo" sandbar, accompanied by erosion along the southeastern edge of the tidal flat and strong accretion in the southwestern area (Duong Quoc Hung et al., 2017).

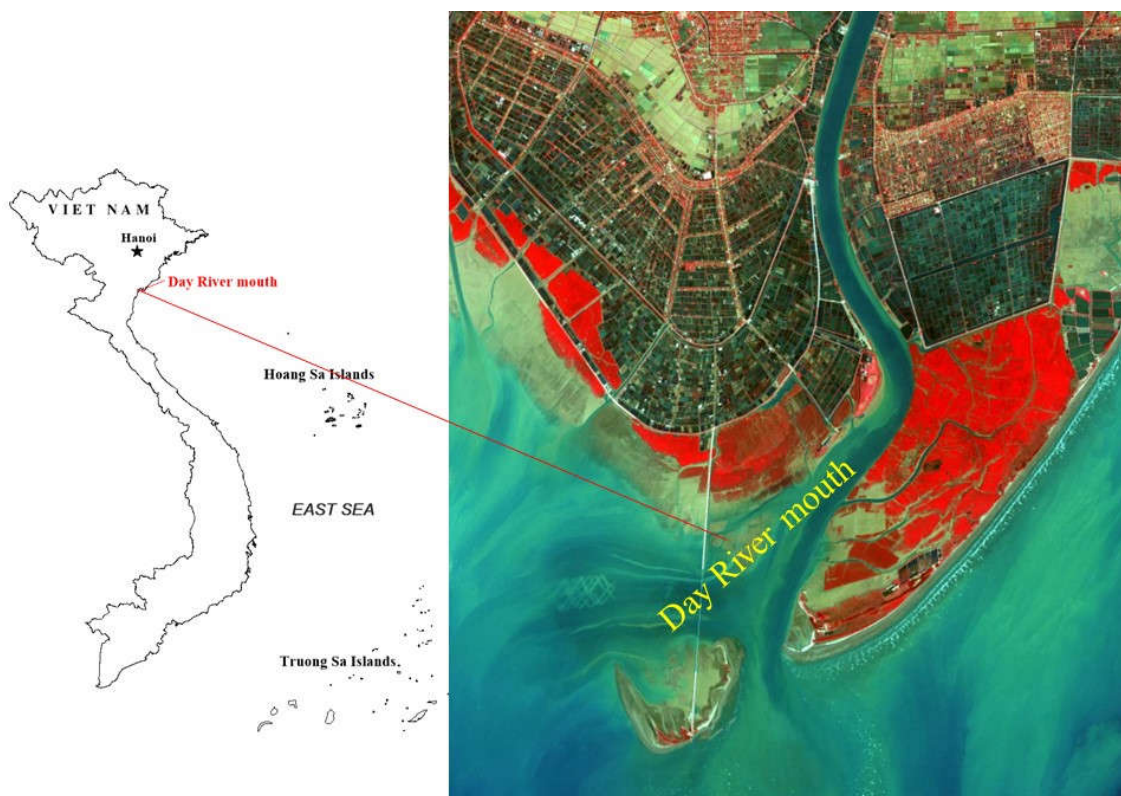


Figure 1. Geographical location of the Day River mouth area

Causes of accretion and erosion: The formation and development of coastal estuarine tidal flats are the result of river–marine dynamic processes, arising from the interaction between natural factors and human activities over a broad spatial scale — from upstream river systems to estuarine zones and along the coastline to depths greater than 20 meters (Nguyen Van Cu, 2006).

The causes of coastal accretion in northern Vietnam in general, and the Day River mouth in particular, result from a combination of natural (both endogenous and exogenous) and anthropogenic factors. *Endogenous factors* are related to geological processes, neotectonic activity, and modern crustal movements that cause uplift, subsidence, extension, and faulting of geological blocks in the coastal zone. *Exogenous factors* include topographic and geomorphological characteristics, as well as climatic elements such as wind, waves, storms, changes in sea level (including global sea-level rise, storm surges, monsoon-induced sea-level changes, and tidal levels), and hydrodynamic forces (tidal currents, wind-driven currents, river flow, wave-induced currents, and sediment transport), resulting from the complex interaction of riverine and marine processes. *Anthropogenic factors* include socio-economic activities and the construction of coastal infrastructure, land reclamation for agriculture, sea dike encroachment, the development of aquaculture ponds, and the influence of hydraulic structures, mining, and extraction of construction materials in the Day estuary coastal area.

Among these factors, exogenous forces play the primary role, with increasing influence from human activities. The states of accretion, stability, and erosion depend on the balance between sediment supply and removal, under the constantly changing influence of exogenous forces, set against the slower, long-term background effects of endogenous processes—which act as reinforcing elements influencing the rate and intensity of erosion–accretion dynamics.

The Day estuary is located in a corner of a shallow, semi-enclosed bay, which is less directly affected by northeast-directed wave action. As a result, the morphological evolution of the Day estuary differs fundamentally from that of other estuaries in the Red River Delta. Specifically, it is characterized by continuous and rapid accretion extending seaward (Nguyen Van Cu, 2006). Both accretion and erosion processes occur in the study area; however, accretion is the dominant process. The Day estuary tends to experience strong accretion due to the abundant sediment supply from the Red River system and the estuary's location within a concave coastal zone, which is sheltered from the dominant wave directions. Although a large volume of sediment is discharged into the sea at the Day estuary, it does not result in the formation of bar-connected accretion patterns like those seen at the Ba Lat, Tra Ly, or Giang estuaries. In this area, in addition to sediment delivered by the Day River, it also receives deposition from longshore sediment transported from the northeast, originating from the Red River (Ba Lat and Ninh Co estuaries). This sediment transport is impeded by the local topography and the flow regime of the Day River, leading to deposition along the shore and filling the space between the Day estuary and the offshore sandbar. As a result, the tidal flat at the Day estuary covers a very large area, and the distance between the offshore bar and the inner tidal flat is almost negligible.

2. Materials and methods

The work was developed based on the results of satellite image analysis and interpretation, field surveys, studies on dynamic geomorphological characteristics, descriptions of surface-layer mud and sand sediments, as well as analyses of grain composition and morphology, and petrographic and mineralogical composition of sediments in the coastal area of Kim Son, including the Day River mouth and Noi island. All of the above analysis results were compiled, processed, and filtered by the research team to extract essential information for

constructing the content of the study. In addition, the project also referenced, processed, and inherited several existing data related to the study area.

Sources of Image Data: The materials used in this study include satellite images, UTM topographic maps, and other relevant documents that recorded the coastal conditions of the Day estuary area at various times from 1965 to 2020 (a span of 55 years). *UTM Topographic Maps (Universal Transverse Mercator):* The Day estuary area is located on UTM topographic map sheets at a scale of 1:50,000, within zone 48, based on the Everest ellipsoid, published by the U.S. Army Map Service (AMS) in 1965–1966 (referred to as "intelligence maps"). *Satellite Images:* Landsat MSS Images (taken in 1965, 1973, 1975); Landsat TM Images (taken in 1989, 1995, 2005, 2009, 2011, 2012). Landsat ETM Images (taken in 2001, 2003, 2005). Landsat OLI Images (taken in 2013–2019). SPOT-2 Images (taken in 1995); Sentinel-2A Images (2017–2020); Sentinel-1 Images (2015, 2017). *Other Related Materials:* These include meteorological, hydrological, and oceanographic data observed at various monitoring stations within the study area, as well as data from field surveys. Additionally, the study referenced several documents and research findings related to geology–geomorphology, coastal dynamics, hydro-meteorology, and the historical evolution of the Northern Vietnam coastal delta plain.

Methods used in this work include basic field investigation of geodesy (on land and underwater by high resolution seismic), hydro-meteorological survey, sample collection and analysis. Especially, remote sensing image analysis methods (GIS) were employed. The method employed in this study involves the interpretation of multi-temporal satellite imagery, topographic maps, and other related documents to analyze the morphological and topographic changes in the coastal area of the Day River mouth.

3. Results and discussion

3.1. The formation and development of coastal flats at the Day River mouth in period from 1965 to 2020 based on geographic information system (GIS) data

To analyze the evolution of the estuary, beaches, tidal flats, shoreline changes, and to assess the formation and development of Con Noi (Kim Son, Ninh Binh), two areas are classified with different time periods for analysis, evaluation, and the creation of thematic maps for specific areas within the research region, as follows

- Kim Son – Nghia Hung coastal zone, from 1965 to 2020
- Day estuary – Con Noi area (Kim Son, Ninh Binh), from 1995 to 2020.

Noi island was first identified in satellite imagery taken in 1995 (SPOT imagery) during low tide. On the SPOT image, submerged sandbars in the Day estuary area were recorded; over time, these submerged bars evolved and changed due to both natural forces and human activities. Therefore, the year 1995 is considered the starting point for the formation of the submerged tidal flats, which served as the foundation for the later development of Noi Island. Over more than 20 years, Noi island has grown and continuously changed its position and morphology, eventually forming the shape observed today.

Below are the results and assessments of the development and shoreline changes, as well as tidal flat evolution in the Day estuary area over the past 50 years (1965–2020). The formation and development of Noi island is specifically focused on the period from 1995 to 2020.

Shoreline and tidal flat changes along the Kim Son (Ninh Binh province) - Nghia Hung (Nam Dinh) coastline during a period from 1965 to 2020.

Figure 2 illustrates the changes in shoreline position in the Day estuary area over the past 50 years (1965–2020). The shoreline on both the Kim Son and Nghia Hung sides has continuously shifted, showing a strong seaward accretion trend, with an average rate of about 100 meters per year. From 1973 to 1989, the Kim Son beach area advanced seaward by up to 2,500 meters at its widest point, with an average accretion rate of 156 meters per year. Between 1989 and 1995, the widest accreted area in Kim Son reached 1,750 meters, corresponding to an accretion rate of nearly 295 meters per year. In addition to natural accretion and the development of mangrove forests, this was also influenced by sea encroachment through dike construction. Thus, it can be seen that the tidal flat in the Kim Son area has expanded seaward rapidly, thanks to active mangrove planting and proactive sea dike construction efforts in the region.

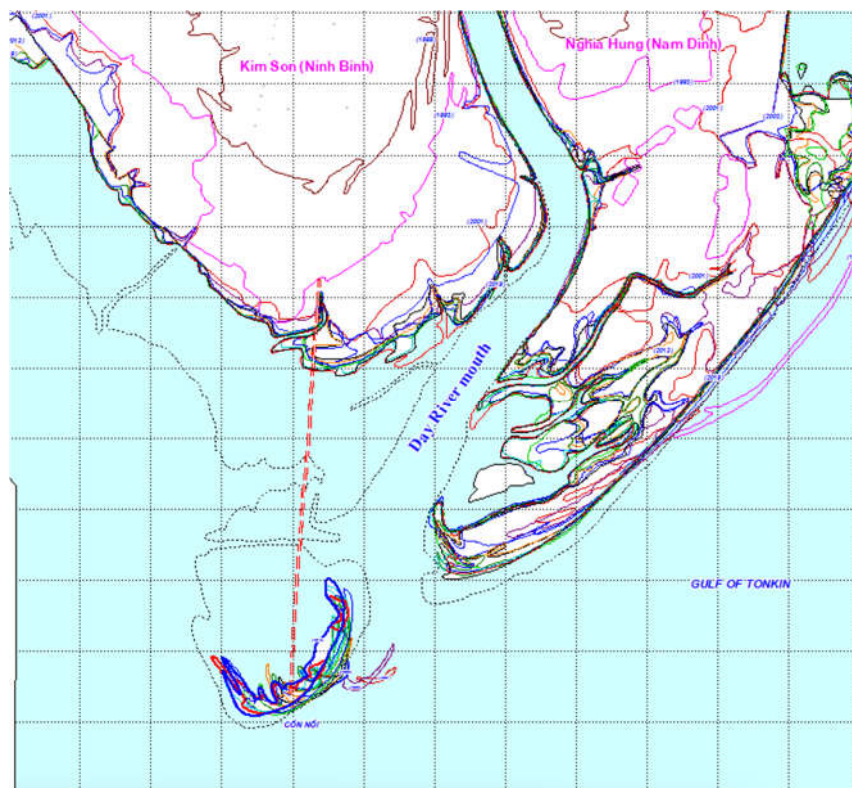


Figure 2. Shoreline position changes in the Day River mouth from 1965 to 2020

Shoreline fluctuations have also been significant on the Nghia Hung side (Nam Dinh Province). However, the accretion–erosion dynamics along the Nghia Hung coast differ from those observed on the Kim Son side. The accreted tidal flat on the Nghia Hung side of the Day estuary has continuously extended southwestward, following a northeast–southwest direction, while the southeastern coastline of Nghia Hung has been subject to ongoing erosion. From 1995 to 2020, the sandbar along the Nghia Hung coast extended up to 3.6 kilometers to the southwest. In contrast, the elevated sand strip visible in 1995 on the Nghia Hung side was completely eroded, with the shoreline retreating inland by up to 750 meters due to severe coastal erosion.

In 1995, a submerged tidal flat (a river mouth bar) began to form in front of the Day River mouth on the Kim Son side. By 2001, this submerged flat had developed and emerged above the water surface, forming a crescent shape - this was Noi island, with an initial length of 590 meters. Subsequently, Noi island continued to grow, gradually expanding in area and shifting westward.

Development of coastal tidal flats in the Day River mouth area

Figure 3 shows the development of coastal tidal flats in the Day estuary area during different time periods from 1965 to 2019. Each stage is represented by numerical labels from (1) to (8) as follows: (1) period 1965–1973; (2) 1973–1989; (3) 1989–1995; (4) 1995–2001; (5) 2001–2005; (6) 2005–2009; (7) 2009–2014; and (8) 2014–2020.

The tidal flats on both sides of the Day River mouth are arranged in a continuous north–south direction, with accretion gradually pushing the estuary seaward (Figure 3). However, the spatial scale and distance between the accreted areas on the Kim Son and Nghia Hung sides differ. On the Kim Son side, the tidal flats have gradually extended toward the south and southeast; in contrast, on the Nghia Hung side, the flats have shifted progressively toward the southwest.

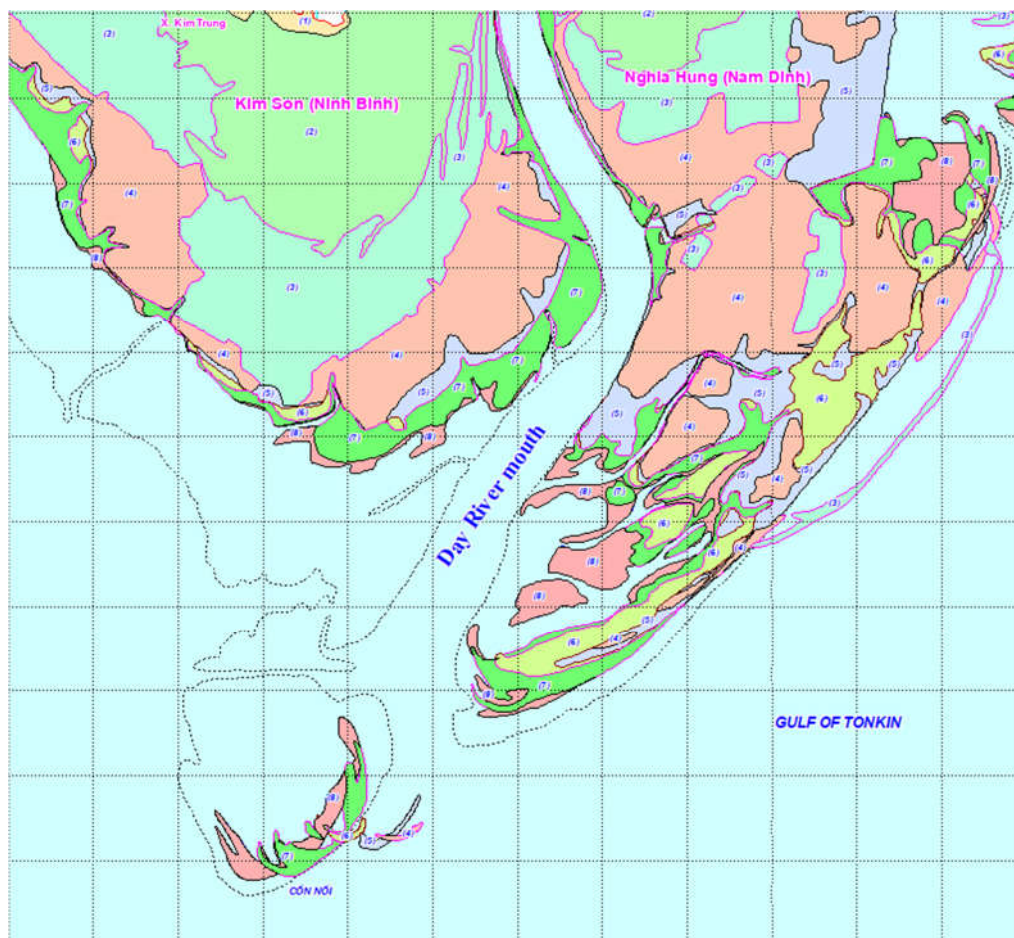
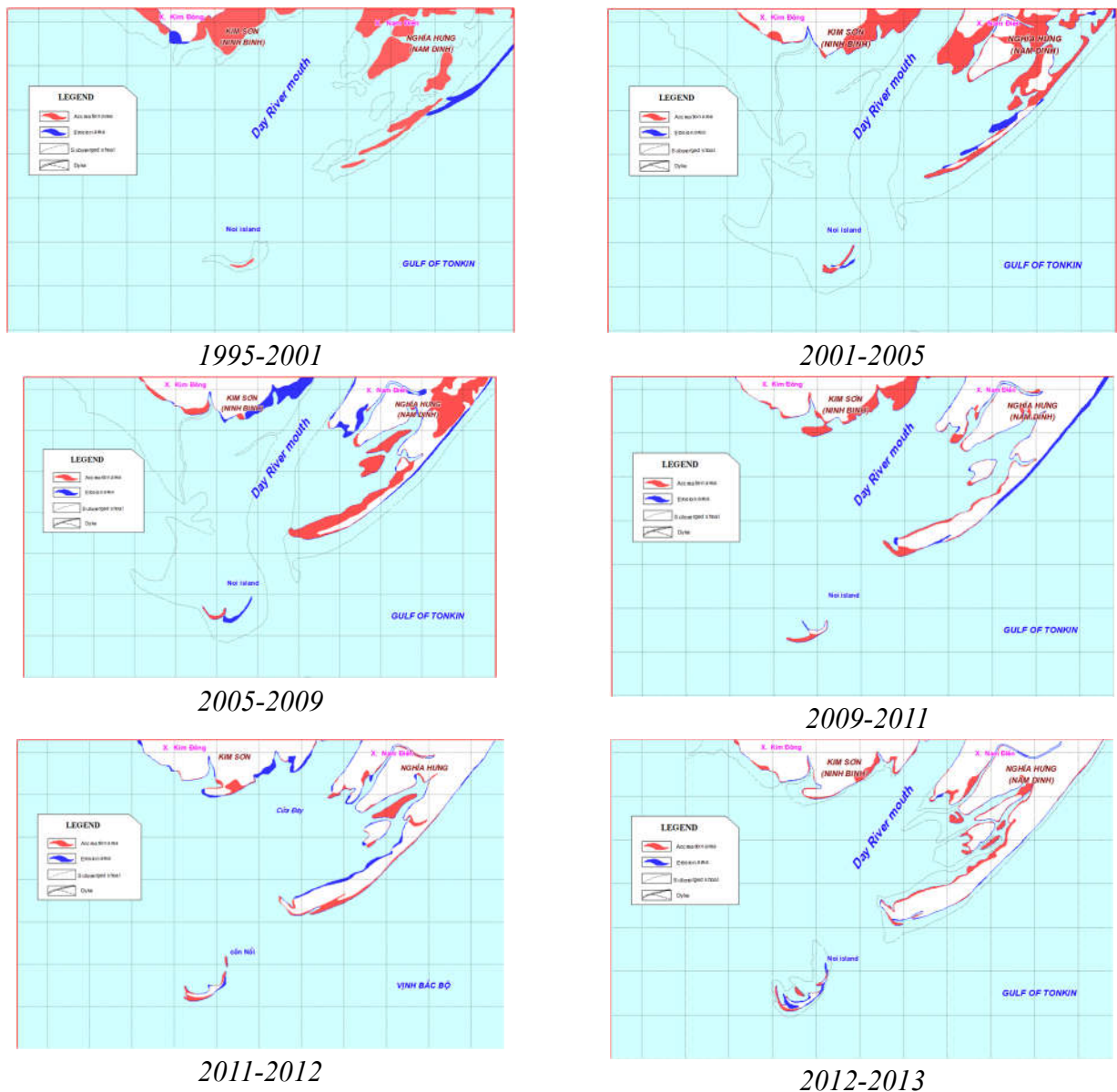


Figure 3. Development of coastal tidal flats in the Day River mouth area, by stages: (1) period 1965–1973; (2) 1973–1989; (3) 1989–1995; (4) 1995–2001; (5) 2001–2005; (6) 2005–2009; (7) 2009–2014; and (8) 2014–2020.

Figure 3 shows that the tidal flats along the Nghia Hung coast tend to be distributed in a northeast–southwest direction. The newly accreted land in Nghia Hung extends and shifts farther south compared to the Kim Son coast by approximately 3 km. Figure 3 also illustrates the general westward migration of Noi island from 2001 to 2020. Noi island has a crescent shape, with its main axis oriented northeast–southwest and both ends tapering toward the shoreline. The morphological development and positional changes of Noi island highlight the strong influence of wave action and currents on both its base and crest.

3.2. Accretion and erosion dynamics in the Day River mouth area from 1995 to 2020

The accretion and erosion evolutions in Day River mouth area from a period of 1995 to 2000 are introduced in Figure 4.



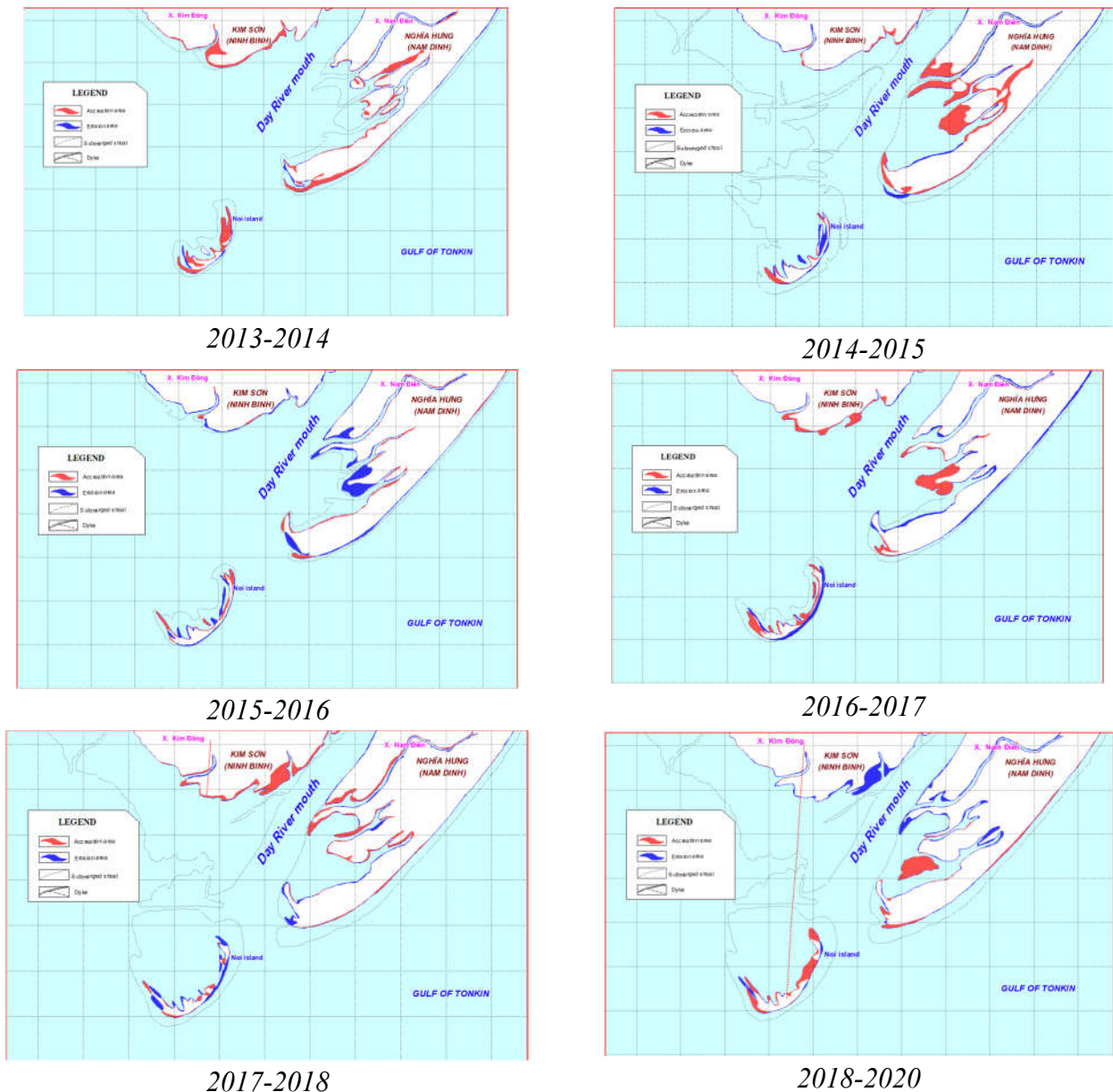


Figure 4. Distribution of accretion and erosion zones in the Day River mouth area, 1995–2020

3.3. Development trend of the Day River mouth over the past 50 years (1965–2020)

From 1965 to 2020, the Day River mouth experienced strong and continuous seaward extension, nearly along a north–south axis. Although the rate of development varied during each short period, overall, the average rate of seaward extension was about 90 -110 m/y - making it one of the fastest-prograding estuaries along the Red River Delta coastline (Duong Quoc Hung et al., 2017; Pham Quang Son, 2004; Phung Van Phach, 2018).

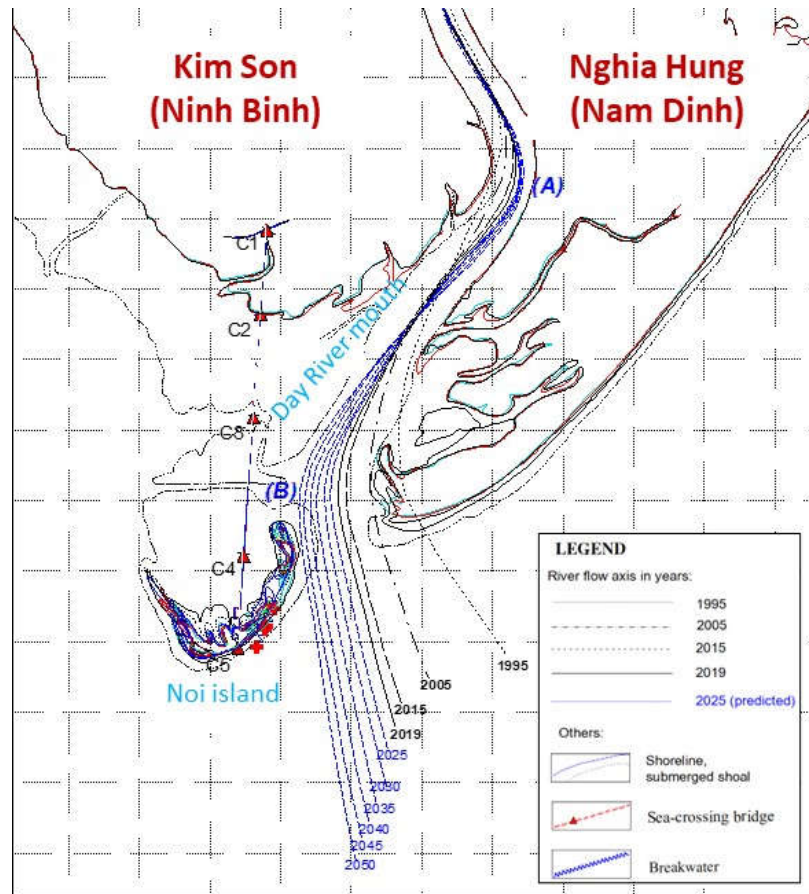


Figure 5. Sketch map of the channel axis shifts of the Day River mouth from 1995 to 2020 and predicted channel changes for the periods 2020–2030–2050

The accretion process along the two banks of Kim Son and Nghia Hung did not occur in the same manner. After 1995, the Kim Son coastline primarily expanded southward, while the Nghia Hung coastline extended mainly southwestward. As a result, the main channel axis of the Day River mouth gradually shifted westward (Figure 5), forming large meander crests at the river mouth - namely crests (A) and (B) - before the Day River discharges into the Gulf of Tonkin. These meander crests (A and B) continue to develop; the distance between them, as observed from 2020, is approximately 5.5 km. Satellite data from 1995 to 2019 indicate that the estuarine channel has constantly shifted, with crest (A) gradually migrating toward the Nghia Hung bank and crest (B) toward the Kim Son bank. Therefore, the southwestward extension of the sandspit along Nghia Hung and the shifting of the meander crests (A and B) over the past two decades reflect the ongoing development of the Day Estuary's channel axis. This provides a foundation for forecasting the estuary's evolution in the coming decades - specifically through 2030 and 2050. The development and morphological changes of the Day Estuary channel are closely linked to the accretion of tidal flats in the coastal zone, particularly in the area of Noi island.

3.4. Forecast of the development trend of the River channel and topography of the Day River mouth

Trend of estuarine channel evolution at the Day River mouth by 2030–2050

Figure 5 shows that the Day River estuarine channel, before flowing into the Gulf of Tonkin, features two pronounced bends at points (A) and (B), which are approximately 5.5 km

apart. Analysis of satellite imagery from 1995 to 2020 reveals that meander bend (A) tends to shift toward the Nghia Hung bank, while meander bend (B) gradually moves toward the Kim Son bank. From 1995 to 2020, meander (A) shifted approximately 320 m toward the left bank (Nghia Hung), corresponding to an average rate of 13.3 m/y. In contrast, meander (B) migrated about 930 m toward the right bank (Kim Son), averaging 38.7 m/y. When broken down into shorter time intervals between 1995 and 2020, the average migration rates of both bends showed a decreasing trend, as summarized in Table 1.

Table 1. Shifts of the curved bends in the Day River mouth channel from 1995 to 2020

#	Stage	Meander bend (A)		Meander bend (B)		Note
		Distance (m)	Average rate (m/y)	Distance (m)	Average rate (m/y)	
1	1995-2005	140	14.0	480	48.0	Significant variation
2	2005-2015	130	13.0	350	35.0	Significant variation
3	2015-2020	50	12.5	100	25.0	Moderate variation
4	1995-2020	320	13.3	930	38.7	

The channel at the Day River mouth is expected to continue extending toward the sea; the meander crest (A) and (B) will further evolve in a curving pattern and gradually shift southward. The projected changes in the positions of the meanders by 2030 and 2050 are as follows:

- By 2030, meander (A) is expected to shift 70–80 m toward the Nghia Hung side, equivalent to a rate of 7–8 m/y. Meander (B) is projected to shift 210–240 m toward the Kim Son side, with an average rate of 21–24 m/y.

- By 2050, meander (A) may shift 160–180 m toward Nghia Hung, with a rate of 5.4–6.4 m/y, while meander (B) may move 530–550 m toward the Kim Son shore, corresponding to a rate of 14.5–15.5 m/y.

The shift of the meander bends (A and B) in the Day River mouth channel is primarily attributed to the prolonged accretion and extension of the sandspit on the Nghia Hung shoreline toward the southwest. Additionally, this process is influenced by the natural fluvial evolution of river channels in deltaic environments, following the inherent laws of channel morphology transformation. These transformations typically occur through distinct stages within a meander cycle, including: (1) straight flow, (2) limited meandering, (3) developing meander, (4) fully developed meander, and (5) return to straight flow, completing the cycle (Nguyen Kien Quyet, 2014; Pham Quang Son, 2004; Phung Van Phach, 2018).

The accretion and extension of the sandspit along the Nghia Hung shoreline is expected to continue in the coming years; however, the rate of expansion will likely decrease due to natural laws and changes in environmental conditions. Moreover, the development process in the Day estuary is taking place within the broader context of climate change, sea level rise, and alterations in river flow regimes. These include changes in sediment transport from the Red River system caused by the construction of large upstream reservoirs for water regulation, as well as river training and shoreline modification activities in the delta and coastal zones. Both natural and anthropogenic changes in the upstream areas directly affect the supply of suspended sediment, which plays a crucial role in the accretion and development of the Red River Delta in general, and the Day estuary in particular.

Detailed forecast of long-term variation trends

The forecast of variation trends is detailed by the following areas and periods

(1) Period 2020–2030

Figure 6 shows a forecast of the changes in coastal accretion areas of Day River mouth during the 2020–2030 Period. The accretion zone in the Day River mouth area will tend to expand seaward as sediment deposition continues to develop. However, each sub-region will exhibit different characteristics and rates of accretion. The area is divided into three main zones: a) Stable accretion zone, b) Unstable accretion zone, and c) Erosion zone (Figure 6); their spatial distribution is as follows:

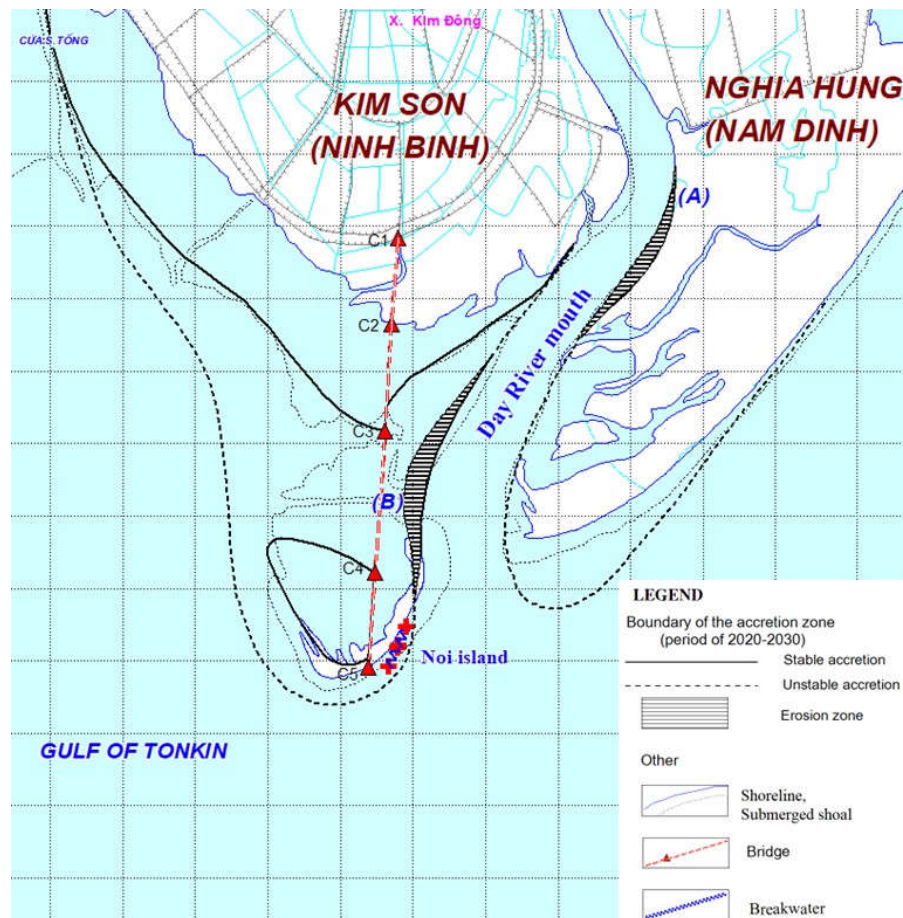


Figure 6. Predicted changes in the coastal accretion areas of Day River mouth during period 2020–2030

a) Stable accretion area

Day River mouth coastline: A strongly stable accretion zone is on the Kim Son tidal flat. The area to the west of the “welded jetty” C2–C3 is expected to experience very strong sediment accumulation due to its sheltered position from the dominant wave directions (east and southeast). As a result, the accreted land may extend seaward at a rate of 80–100 m/y. The western tidal flat, belonging to the stable accretion zone, has a width ranging from 800 to 1,000 m. The stable accretion zone east of the C2–C3 “welded jetty” is narrower in extent, with seaward advancement ranging from 200 to 500 m.

Noi island area: The *stable accretion* area is located in the wave-sheltered zone to the northwest of the current dune crest. The stable accretion zone is protected by the section of the “welded jetty” C4–C5 and the highest point of Noi island. The topography of this stable accretion area is less affected by wave action and is protected by a natural sand dike covered with vegetation, mainly *Casuarina* species planted to stabilize the soil and prevent sand drift. To the east, this terrain is further shielded by the C4–C5 coastal road, which has been reinforced with concrete to resist wave and wind erosion. The accreted area has favorable conditions to gradually expand northwestward. It is projected that by 2030, the stable accretion zone in the northern part of the island will cover an area of approximately 160 to 170 ha. This will be the primary area for the development and utilization of Noi island in the coming decade.

b) Unstable accretion areas

This area is identified as a shallow-water zone adjacent to the stable accretion area, with potential for aquaculture development. Although strong sediment accumulation occurs in this shallow zone, the seabed topography remains unstable due to the influence of currents and wave action. These conditions lead to the formation of mobile submerged sandbanks, which can be eroded or destroyed during storms or strong monsoon events. The unstable accretion zone along the Kim Son coast covers a relatively large area and serves as a foundation for the future development of coastal accretion zones.

c) Erosion areas

This zone is identified as the nearshore and submerged sand bar area distributed along the main channel, particularly at the meander bends (A) and (B). At these bends, the channel depth is typically greater, and the cross-sectional profiles are asymmetrical. These are unstable riverbank areas where intense shoreline erosion occurs due to high flow velocities, especially during flood seasons. The erosion is most severe during periods of strong ebb tides combined with floodwaters flowing seaward from the river. The strong currents with high velocities at the meander bends create deep scour trenches. The eroded shoreline zones along the main channel of the Day River mouth extend approximately 2.5 km at bend A and up to 3.5 km at bend B. The maximum width of the erosion zone ranges from 160–180 m at bend A to 250–270 m at bend B.

(2) Period 2030 -2040

a) Stable accretion areas

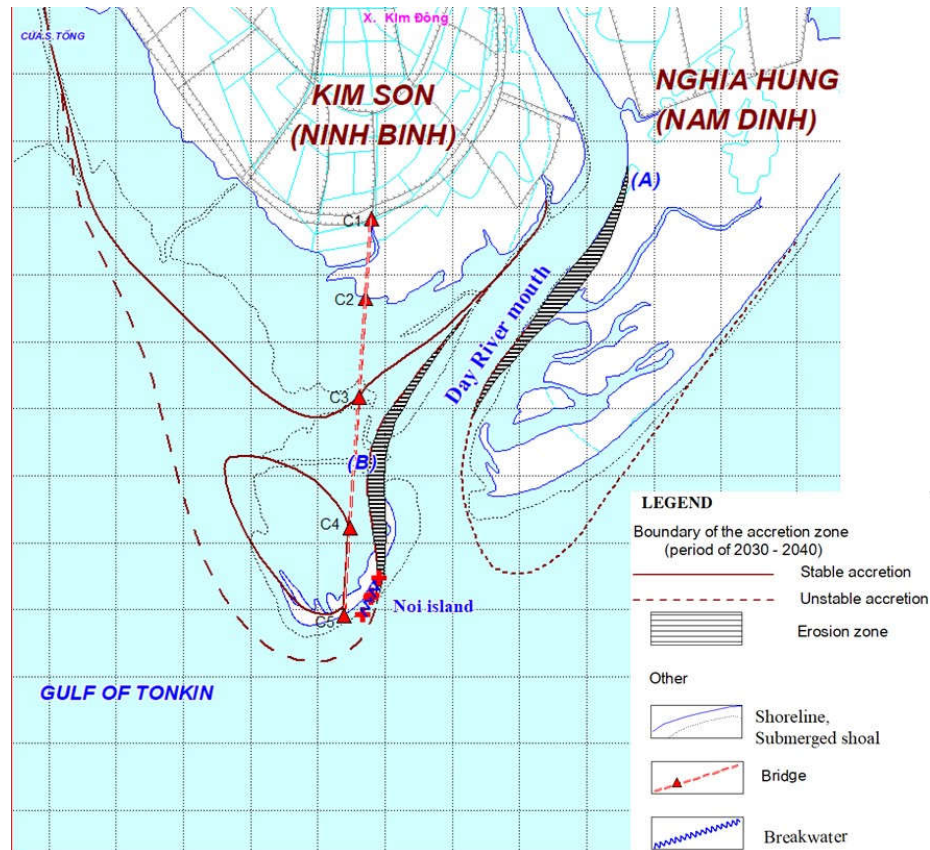


Figure 7. Predicted changes in the coastal accretion areas of Day River mouth during a period 2030 -20240

Day River mouth coastline: The tidal flats in the Day River mouth area are continuing to experience strong sediment accretion. The stable accretion zone has expanded into areas that were previously classified as unstable accretion zones, due to the abundant sediment supply and the zone's location in a region less affected by wave action and coastal currents (Figure 7). The stable accretion zone along the Day River mouth coastline has expanded seaward by 400 to 750 m, corresponding to an accretion rate of 40-75 m/yr. The area of the stable accretion zone (located seaward of the current shoreline) is estimated to range from 1,350 to 1,400 ha (Figure 7). This area has potential for exploitation in the agriculture–forestry–fishery sectors and serves as a foundation for future land reclamation and sea encroachment efforts along the Day River mouth coast

Noi island area: The area continues to expand northwestward and is projected to reach a size of 270 to 280 hectares (Figure 7). The process of sediment accretion and spatial expansion along the northwestern shoreline of Noi island, together with the southward extension of the Kim Son accretion zone, reflects a trend toward the progressive connection between Con Noi and the Kim Son mainland in the next phase of development.

b) Unstable accretion areas

This area is identified as a shallow coastal water zone, with spatial expansion compared to the previous period (Figure 7). The seafloor topography in this shallow-water region remains dynamic due to the influence of waves and coastal currents, with the strongest impacts

occurring during storms, tropical depressions, or major floods. This zone has potential for aquaculture development.

c) Erosion areas

The erosion-prone areas have been identified along the margins of the Day estuary channel, particularly where meander bends (A and B) are developing. These bends are still in the meandering development phase, continuing to evolve and migrate, accompanied by bank erosion on both the Nghia Hung and Kim Son sides (Figure 7). However, as the channel gradually progresses toward the "fully developed meander" stage, the rate of meander curvature and channel migration is expected to decrease, leading to less intense erosion and slower movement of the meander bends compared to the previous period.

(3) Period 20230 -2040

a) Stable accretion areas

Along the coast of the Day estuary and the northern part of Noi island, the accretion continues to expand toward the point of connection between Noi island and the mainland, forming a "post-island" accretion landform in the shape of a Tombolo (hammerhead). The Day estuary is effectively extending seaward, nearly along a north–south axis — which is also the main directional orientation of river mouths in the southern part of the Red River delta. The stable accretion zone covers an area of approximately 1,900 ha and is projected to become the new coastal area of Kim Son during the 2040–2050 period (Figure 8).

b) Unstable accretion areas

This area is adjacent to the stable accretion zone. It is a shallow-water region of potential for aquaculture development. In addition to ongoing sediment accumulation, the seabed topography here may fluctuate due to wave action and coastal currents, especially under storms, tropical depression, or major flood conditions. Although the rate of tidal flat accretion is expected to decrease compared to previous periods, this remains the most actively accreting coastal zone in the Red River Delta.

c) Erosion areas

The area is gradually shrinking as the meander bends approach a stage of "fully developed curvature." The Day River mouth is expected to become more stable, with the main channel axis extending seaward in a direction nearly aligned with the north–south axis (180–200°) (Figure 8).

The shallow-water area in front of the Day River mouth represents a dynamic interface between river and marine forces. This zone has favorable conditions for the formation of new submerged sandbars (bars), which act as the initial nuclei for accretion and could potentially develop into a new generation of islets following Noi island. Currently, a shallow-water area has been observed approximately 1.5 km southeast of Noi island, where the water depth is about 1–3 m shallower than the surrounding area. This can be seen in satellite imagery as a zone of concentrated wave breaking (Figure 8) and is considered a potential new accretion island.

This type of landform is common at river mouths in the Red River Delta. The development and shifting of these submerged bars in front of the estuary often divide the main

channel into smaller distributaries, which can hinder waterway navigation. Therefore, to ensure safe passage, it is necessary to implement navigation channel management measures—an effort that is currently ongoing.

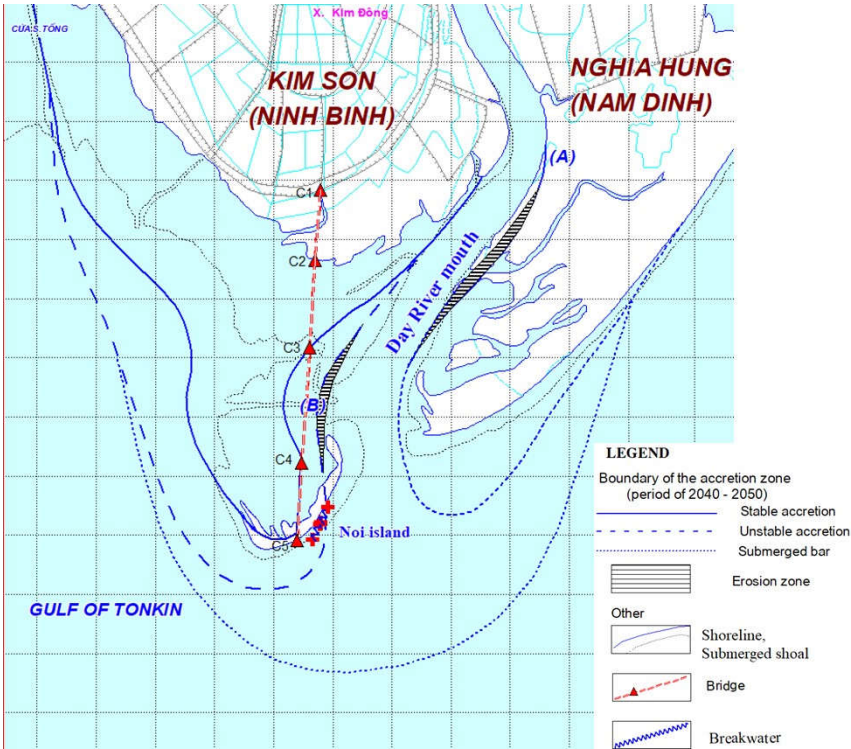


Figure 8. Predicted changes in the coastal accretion areas of Day River mouth during a period 2040-2050

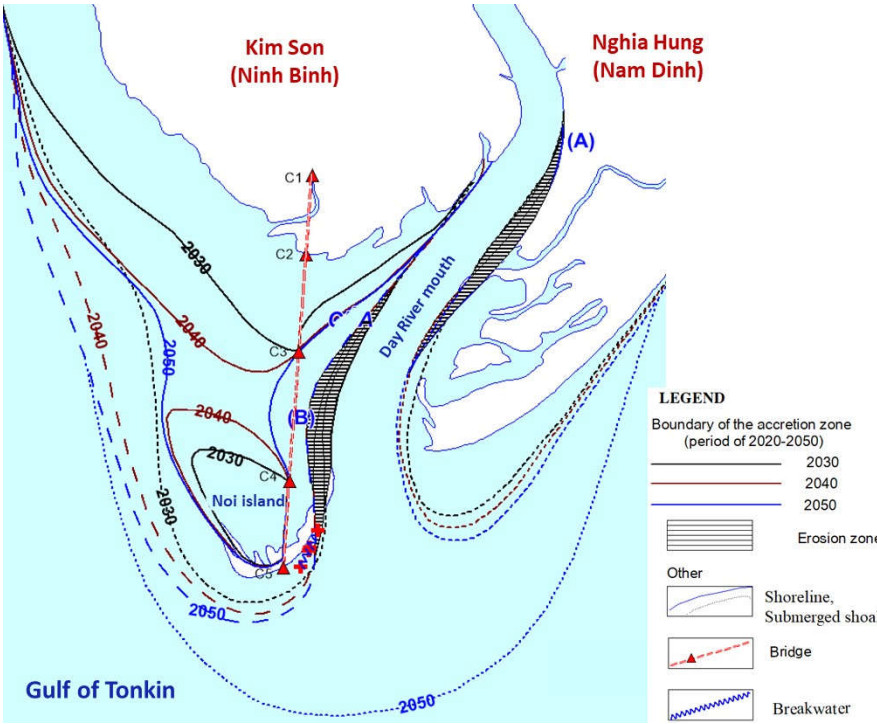


Figure 9. Predicted changes in the coastal accretion areas of Day River mouth during a period 2030-2050

The above forecasts regarding the potential development of the coastal landforms in the Day River mouth take into account natural conditions, including the impact of sea level rise based on the scenarios published by the Ministry of Natural Resources and Environment in 2016 (with projected sea level rise ranging from 21 to 25 cm), as well as the influence of existing engineering structures. These include the road and overpass leading to Noi island and the wave protection embankments to the east and southeast of Noi island. However, the forecasts do not account for the potential impacts of future engineering works that may be constructed in this area, such as dredging of navigation channels, construction of channel training structures, mangrove forest planting, land reclamation dikes, coastal aquaculture development, and other related activities.

General Assessment

The Day estuary area is expected to undergo significant changes during the periods 2020–2030 and 2030–2050 due to both natural and human-induced factors.

- Impacts of climate change are mainly associated with the increasing frequency and intensity of extreme weather events such as heavy rainfall, major floods, and strong to very strong storms (including super typhoons). The direct impact of sea level rise is currently moderate, roughly equivalent to water level increases caused by monsoonal winds (less than 30 cm).

- Coastal engineering structures, including the road and bridge connecting to Noi island, in addition to their role as transportation infrastructure, also positively contribute to sediment accumulation and the stabilization of the coastal accretion zones in Day River mouth area..

- By 2030, strong sediment accretion is projected along the Kim Son coast and the northern part of Con Noi, due to limited wave impact (wave divergence effect in sheltered zones). Furthermore, the sediment supply in the Day River mouth coastal zone remains abundant, primarily provided by the Red River system.

- By 2050, the space between the Kim Son coast and Con Noi is expected to be entirely accreted, creating a landform that connects the mainland to the offshore sand island, forming a tombolo-type structure.

- The main erosion zones are located along the Day River mouth channel, particularly in the areas of developing meander bends. Riverbank and channel bed erosion is expected to gradually decrease as these meanders mature and reach a "fully developed curvature" phase.

- The Day estuary will continue extending seaward along a near north–south axis. Submerged sandbars (bars) are forming at the estuary mouth. These dynamic and growing bars will likely divide the main channel into primary and secondary branches, which can obstruct navigation. As such, further hydraulic studies and navigational channel adjustments are necessary to ensure safe and effective waterway access.

4. Conclusions

The coastal accretion zone of Day River mouth is located in a shallow-water area resembling a semi-enclosed bay, which is minimally affected by direct impacts from the

northeast wave direction. As a result, the evolution of the Day estuary differs fundamentally from that of other river mouths in the Red River Delta. Specifically, it undergoes continuous and rapid sediment accretion and extension toward the sea.

The factors influencing erosion and accretion in the coastal area of Day River mouth include endogenous, exogenous, and anthropogenic factors. Among these, exogenous factors play a dominant role, especially in combination with the increasing influence of human activities. The formation and development of Noi island are governed by both exogenous and anthropogenic factors. The sediment supply that forms the accretion plain and Noi island primarily originates from floodwaters of the Day River, followed by long-term littoral drift transporting sediment from north to south along the coast.

The study on the formation and development of the coastal accretion zone in the Kim Son area over a period of 55 years (1965–2020) and of Noi island over 25 years (1995–2020) reveals several key patterns:

- The shoreline of Kim Son has continuously expanded and extended seaward, primarily in a southern and southeastern direction. The southeastern shoreline, which also faces the main wave direction at the Day River mouth, is experiencing strong erosion.
- The extended sediment accumulation in the form of a large sand spit from the Nghia Hung side has caused a westward shift of the main channel axis at the Day River mouth.
- The coastal zone of the Day estuary is expected to undergo significant changes during 2020–2030 and 2030–2050 due to both natural and anthropogenic impacts. The climate change effects are mainly attributed to the increasing occurrence of extreme weather events, such as heavy floods, and strong to very strong storms. The direct effect of sea level rise remains modest, roughly equivalent to the rise caused by monsoonal wind activity.
- Coastal engineering structures, including the road and bridge connecting to Con Noi, not only function as a transportation corridor but also contribute positively to sediment accretion and the stabilization of the coastal landforms in the Day estuary.

Forecast for the 2030–2050 Period

By 2030, strong sediment accretion is expected along the Kim Son coastline and in the northern area of Noi island. The sediment supply in the coastal zone of the Day River estuary remains abundant, primarily fed by the Red River system.

By 2050, the space between the Kim Son coast and Noi island is projected to become fully accreted, forming a landmass that connects the mainland to the nearshore sandy islet. This will result in the development of a Tombolo-type landform

The main erosion zone is located along the Day estuary channel, particularly in areas where meander bends are developing. The erosion of riverbanks and the channel bed is expected to gradually decrease as the meander bends evolve and reach the "fully developed curvature" stage.

The Day estuary will continue extending seaward, nearly along a north–south axis. Submerged sandbars (bars) will form at the river mouth. These mobile and growing bars will divide the main channel into primary and secondary branches, obstructing navigation routes

into and out of the estuary. Therefore, further study and channel interventions will be necessary. These evolving submerged bars are expected to grow larger and could serve as sediment nuclei for the formation of future generations of sandbars or emerging islets.

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