Vietnam Academy of Science and Technology

Vietnam Journal of Marine Science and Technology

journal homepage: vjs.ac.vn/index.php/jmst

Application of GIS and remote sensing in detecting coastal reclamation in the coastal areas of Hai Phong - Ha Long from 1990 to 2020

Do Thi Thu Huong*, Tran Dinh Lan, Nguyen Thi Thu Ha, Nguyen Dac Ve, Nguyen Van Thao

Institute of Marine Environment and Resources, VAST, Vietnam

Received: 17 May 2024; Accepted: 2 November 2024

ABSTRACT

Coastal reclamation transforms coastal areas into usable land for urban, agricultural, and industrial purposes. This study evaluates the status of coastal reclamation from 1990 to 2020 in the Hai Phong - Ha Long coastal area using high and medium-resolution satellite images and GIS techniques. The findings revealed a significant increase in reclamation activity, with 900 hectares reclaimed in 1990–2000, 3,161 hectares in 2000–2010, and 3,434 hectares in 2010–2020. Over different periods, the objectives of reclamation activities shifted. In 1990-2000 and 2000–2010, the focus was primarily on facilitating aquaculture and mangrove cultivation. However, from 2010 onwards, the focus shifted to the developing industrial parks, urban areas, and recreational spaces. Coastal reclamation activities have led to changes in the coastline's characteristics, including length and shape alterations. Over 30 years, the total coastline length has increased by 58.4 km, with the proportion of artificial coastlines increasing by 33.5%. Additionally, coastal reclamation has converted significant areas of mangrove forests, tidal flats, and shallow coastal waters into new land. Therefore, strong policies and integrated coastal zone management are needed to ensure sustainable development and preserve coastal ecosystems.

Keywords: Coastal reclamation, coastline change, coastal reclamation index, Hai Phong, Ha Long.

*Corresponding author at Institute of Marine Environment and Resources, 246 Da Nang, Ngo Quyen, Hai Phong, Vietnam. *E-mail addresses*: huongdt@imer.vast.vn

https://doi.org/10.15625/1859-3097/20808

INTRODUCTION

Coastal reclamation is a process of transforming coastal areas into usable land, and it is a widespread activity globally aimed at urban, agricultural, and industrial development. Coastal reclamation activities are particularly prevalent in East Asia, the Middle East, Southeast Asia, Western Europe, and West Africa [1]. Even many countries such as England, Singapore, Hong Kong, and Macau have begun economic development and urban construction through coastal reclamation in the past [2, 3]. The proportion of territorial land acquired through coastal reclamation in Singapore, Hong Kong, and Macau account for 10, 5 and 33% respectively [4]. The role of coastal reclamation in resolving difficulties caused by land shortages in big cities is undeniable. However, coastal reclamation can harm the coastal environment by destroying ecosystems and causing the water quality degradation. These impacts significantly affect on ecological safety and sustainable coastal development if there are no adaptation solutions. Therefore, understanding the status of coastal reclamation is important for the management and sustainable use of coastal areas, and for proposing solutions to manage and utilize marine space.

Remote sensing data is used to monitor coastal reclamation activities due to its ability to provide and update comprehensive spatial information over large areas and the diversity of data series over time. The application of remote sensing to monitor coastal reclamation activities has recently become quite popular in many Asian countries, especially developing nations like China, Malaysia and Indonesia [1, 5–10]. Coastal reclamation has become a popular activity accompanying the development of coastal urban and residential areas. Integrating remote sensing and GIS technology allows for determining the area of coastal reclamation, identifying leveling types, and assessing changes over time by leveraging the strength of remote sensing image data.

Integrating remote sensing data with GIS technology can enhance spatial analysis and visualization of coastal reclamation activities. Many studies have demonstrated the potential to use GIS tools and spatial modeling techniques in assessing the environmental impacts of coastal reclamation, identifying vulnerable coastal areas, and supporting the decision-making process [11–13]. Furthermore, the use of remote sensing and GIS aids in quantifying the processes and extent of changes in coastlines and coastal mudflats resulting from natural processes and human activities in coastal areas [14–17]. These studies also emphasize the importance of addressing issues related to data accessibility, cost-effectiveness, and capacity building in developing countries where coastal reclamation is prevalent. Some research has shown the effective of applying remote sensing image data to evaluate the relationship between coastal reclamation and total suspended solids (TSS) increases in seawater environments [18]. Yu et al., (2021) examined sea reclamation data from 1980 to 2018 in Guangxi Beibu Bay (China), based on the result, they proposed integrated coastal zone management decisions [11].

In Vietnam, land reclamation activities have a long history, dating back when our ancestors reclaimed and opened new lands [14]. Land reclamation is a way to expand land resources, drive socio-economic development, and adapt to climate change and rising sea levels [19]. However, in recent years, there has been a significant increase in the pace of sea reclamation, particularly in large coastal cities, due to urbanization and industrialization trends. Coastal cities like Da Nang, Nha Trang, Hai Phong, and Ha Long have undergone rapid urbanization, expanding toward the sea. While coastal reclamation brings benefits such as providing additional land for infrastructure, altering the cityscape, and boosting the GDP through large projects, it has also led to environmental issues, disputes over natural resource usage, and the destruction of vital marine ecosystems. This study aims to evaluate the status of sea reclamation from 1990 to 2020 using high and medium-resolution satellite images acquired in the study area (Fig. 1). The mechanisms of coastal reclamation activities and their purposes are also revealed.

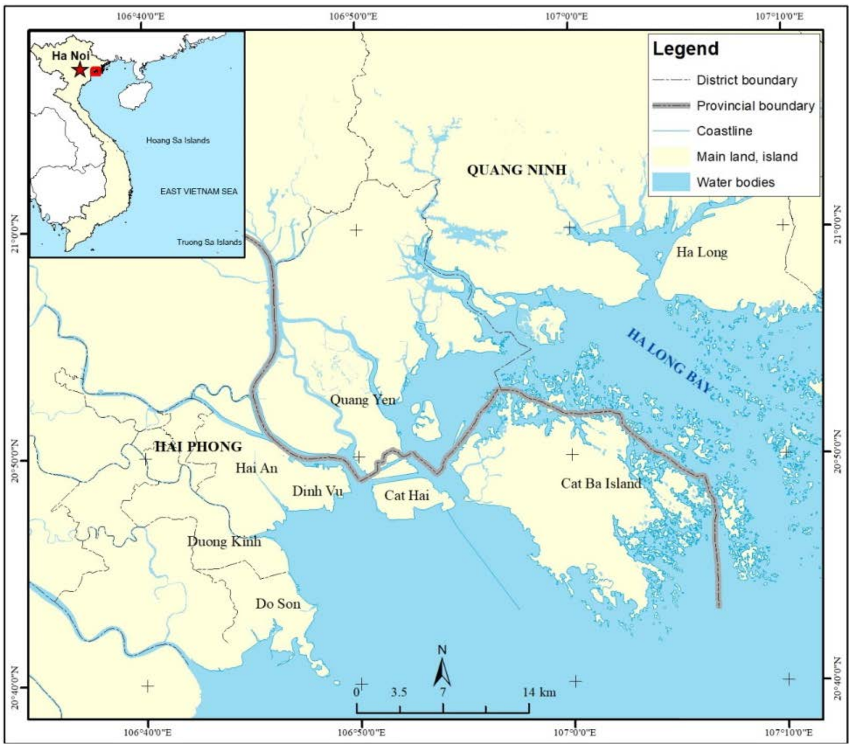

Figure 1. The study area

MATERIALS AND METHODS

Materials

Satellite data was collected from different sources: SPOT and ALOS AVNIR image data were stored at Marine Environment and Resource; Landsat and Sentinel images were free to download from relevant websites (Table 1). Except for the Landsat images, those images have the same resolution of 10 m.

Table 1. List of satellite images used

Date of image acquisition	Image Sensor	Source
7/9/1990	Landsat	www. Usgs.com
5/11/2000	SPOT 4	Remote Sensing database stored at the Institute of Marine Environment & Resources
23/10/2010	ALOS AVINIR	Japan Aerospace Exploration Agency (Jaxa)
22/10/2020	SENTINEL 2	https://dataspace.copernicus.eu/

Geometric rectification

The Landsat images acquired in 1990 were geometrically rectified to UTM coordinates (Datum: WGS84, Zone 48 North) through image-to-image registration, utilizing data from NASA's global orthorectified LANDSAT archive as a reference. The corrected images were used to rectify the other images from 2000, 2010 and 2020. Rectification employed the nearest neighbor resampling routine, ensuring the root-mean-square error was less than one pixel in all cases.

Extraction of coastline

Coastline extraction is one of the important steps in determining the extent of coastal reclamation over different periods. Several coastline extraction methods exist, such as automatic, semi-automatic, and visual interpretation. Regardless of the method used, expert knowledge about the reality of the research area is crucial and dramatically influences the accuracy of the results. Therefore, many studies have shown that visual interpretation gives the most accurate results [20–22]. The coastline on satellite images is determined as the boundary between land and water at the time of image acquisition and may vary at different times due to tidal influences. Therefore, we attempted to select images with similar tidal heights to minimize errors.

This study used automatic and visual interpretation methods to extract the 1990, 2000, 2010, and 2020 coastlines. Additional knowledge about the topography of the research area was combined during image processing. The coastlines for 2000, 2010, and 2020 are extracted based on the positional fluctuations of the corresponding coastline in 1990 to minimize errors between years. Errors related to satellite image interpretation and digitization were quantified to understand accumulated errors from image correction, digitization, and fluctuations in tidal levels at the time of image acquisition. Apply standard deviation calculation to shoreline locations by repeatedly digitizing the same coastline segment across multiple satellite images to determine the error range of all shoreline locations [12]. In this study, the error range determined was from 10 m to 20 m.

After being extracted from satellite images, the coastline was classified as natural or artificial based on the degree of human modification. Artificial coastlines include dikes, breakwaters, aquaculture ponds, salt fields, construction embankments, and wharves. Natural coastlines include bedrock, mud tidal flats, beach, biological, and estuarine. Coastline length is determined according to Dung B.Q & Khanh U.D.'s method [23].

Extraction and classification of coastal reclamation

The status of coastal reclamation in the Hai Phong - Ha Long area during the period of 1990–2020 was determined by assessing the fluctuations in coastline at different times, obtained from satellite image data. Overlaying coastlines from different times allows us to determine the reclaimed areas. The areas of reclamation sites during the periods 1990–2000, 2000–2010, and 2010–2020 were determined and analyzed using ArcGIS software. To evaluate the characteristics and purposes of coastal reclamation activities, types of coastal reclamation were classified into the following categories: construction land, aquaculture land, industrial land, beaches, and mangrove forests. Coastline retreat due to removing aquaculture dykes, digging channels to open creeks, and erosion, leading to shifting of the coastline towards the mainland, was not evaluated in this study.

Coastal reclamation is usually used in urban planning, construction, land resources, and coastal development [11]. The intensity of land reclamation is often measured by the proportion of land used for development. The intensity and magnitude of land reclamation are often calculated by the coastal reclamation index (*CRI*). *CRI* is used to determine the area of reclamation per kilometer of coastline per year in the study area during a specific period and is calculated according to the formula (1) [12].

$$CRI = \frac{A_p}{Y_p \times \left(L_{y1} + L_{y2}\right)/2} \quad (1)$$

where: CRI: the intensity index of coastal reclamation; Y_p: the number of years of coastal reclamation from *y*1 to *y*2; A_p: the area of coastal reclamation over the period from *y*1 to *y*2; L_{y1}, L_{y2}: the coastline length in the year *y*1 and *y*2 respectively.

RESUlTS

Coastline change

The characteristics of the coastline in the study area were significantly altered due to coastal reclamation activities, affecting its length and shape (Fig. 2 and Table 2). In 1990, the total coastline length of the study area measured 385.7 km, with the rate of artificial coastline accounting for 13.65%. By 2000, the total coastline length had increased to 394.1 km, with artificial coastline contributing to 37.6% of the total. In 2010 and 2020, the total coastline length increased to 408 km and 444.2 km, respectively, with artificial coastline ratios of 50.3% and 47.1% (Table 2). Over 30 years, the coastline length of the study area increased by 58.4 km, with the proportion of artificial coastline increasing by 33.5%. The increase in the proportion of artificial coastlines is attributed to coastal reclamation activities for constructing ponds for aquaculture, embankments to reclaim land from the sea for industrial parks and recreational areas, and the construction of wharves, breakwaters, and other infrastructure. These activities have replaced the natural coastline with artificial features.

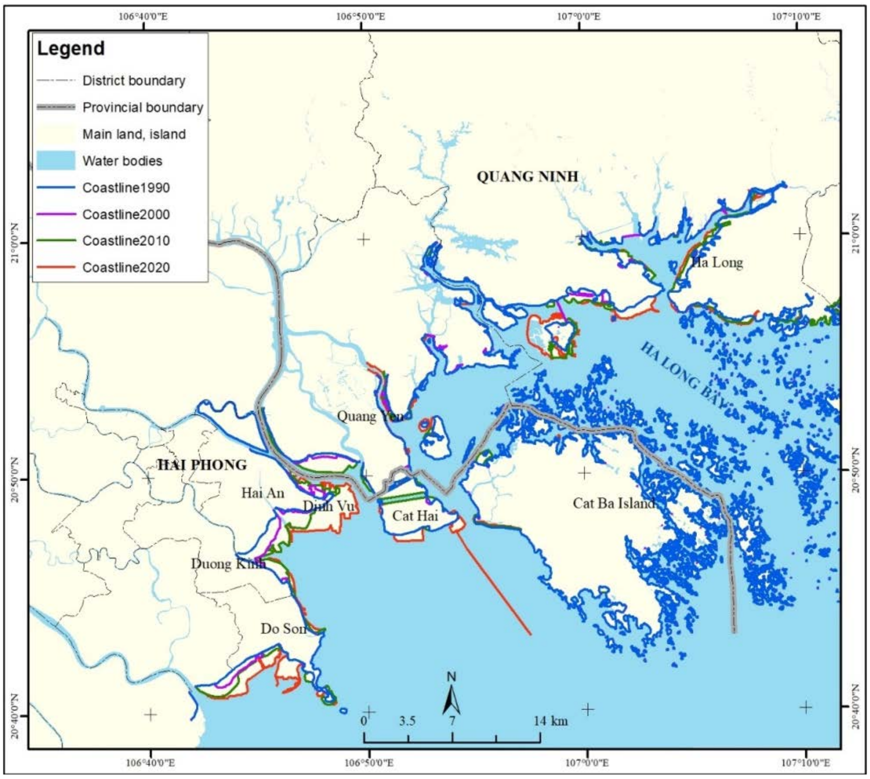

Figure 2. Spatial distribution of coastline in Hai Phong - Ha Long coastal area from 1990–2020

Table 2. Change in coastline length from 1990–2020

Location	1990			2000			2010			2020		
	Total length (km)	A.C (%)	N.C (%)	Total length (km)	A.C (%)	N.C (%)	Total length (km)	A.C (%)	N.C (%)	Total length (km)	A.C (%)	N.C (%)
Cat Hai island	30.0	46.5	53.5	23.7	84.7	15.3	28.55	89.8	10.2	41.76	88.1	11.9
Dinh Vu	46.0	28.7	71.3	37.5	45.5	54.5	41.74	55.5	44.5	51.86	38.2	61.8
Do Son	29.5	43.2	56.8	35.4	27.6	72.4	38.93	30.3	69.7	52.81	41.1	58.9
Ha Long	174.8	0.2	99.8	165.7	26.2	73.8	166.03	40.7	59.3	178.58	49.0	51.0
Quang Yen	105.3	11.7	88.3	131.8	44.0	56.0	132.74	58.0	42.0	119.15	36.6	63.4
Total	385.7	*13.6*	*86.4*	394.1	*37.6*	*62.4*	408.0	*50.3*	*49.7*	444.2	*47.1*	*52.9*

Notes: A.C- artificial coastline; N.C- natural coastline.

Change in coastal reclamation from 1999 to 2020

From 1990–2000, the total area of coastal reclamation in the study area was about 900 hectares, concentrated mainly in the area around Dinh Vu Island and the Do Son area. Common purposes for coastal reclamation activities at this stage include planting mangrove forests and constructing dikes and dams for aquaculture. Of these, the area designated for mangrove planting accounts for 64% of the total coastal reclamation area, while the area allocated for aquaculture accounts for 22%.

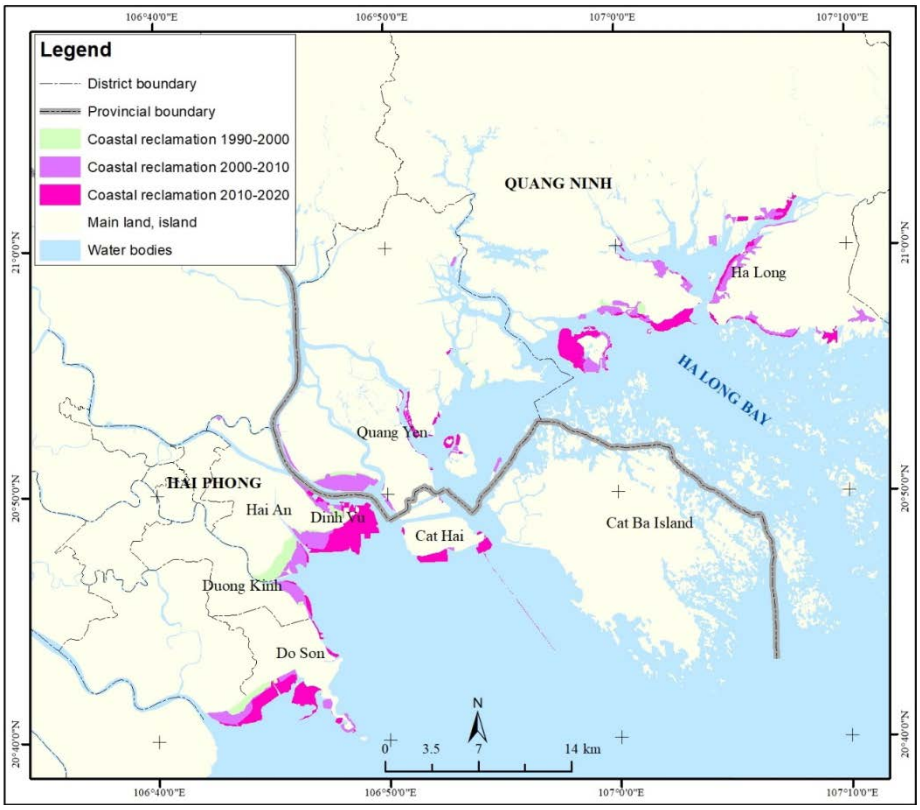

Figure 3. Spatial distribution of coastal reclamation from 1990–2020 in Hai Phong - Ha Long coastal area

From 2000 to 2010, the total coastal reclamation area in the study area was 3,161 hectares. Coastal reclamation during this period was mainly distributed in the areas of Ha Long (Quang Ninh), Dinh Vu, and Do Son (Hai Phong) (Fig. 3). The area around Ha Long had the largest coastal reclamation area, about 40%. The primary purpose of coastal reclamation during this period was aquaculture activities and construction land, which accounted for 41% and 42% of the reclaimed areas, respectively. Additionally, 13% of the total reclamation area was recorded for mangrove planting activities.

From 2010 to 2020, the total reclamation area was 3,434 ha. At this stage, Ha Long had the largest reclamation area, covering 1,270 ha, which accounted for 35% of the total reclamation area (Fig. 4). Dinh Vu and Do Son comprised 27% and 25% of the reclamation area, respectively. The remaining areas had insignificant reclamation activity. The primary purpose of coastal reclamation during this phase was to create land for infrastructure supporting socio-economic and recreational activities, which accounted for 79% of the total reclaimed area. About 19% of the remaining reclamation area was dedicated to mangrove planting. This period also witnessed a highlight as mangrove planting projects were successfully implemented in the southern area of Do Son. The total area of mangrove forests increased by about 664 hectares during this period.

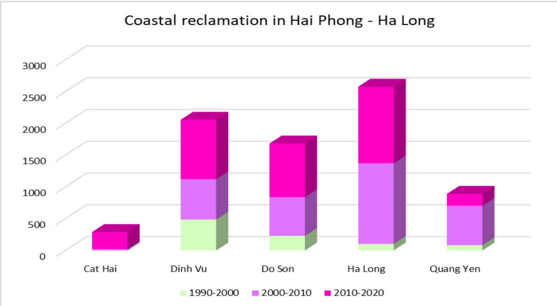

Figure 4. Changes in coastal reclamation area in Hai Phong - Ha Long from 1990–2020

Coastal reclamation intensity

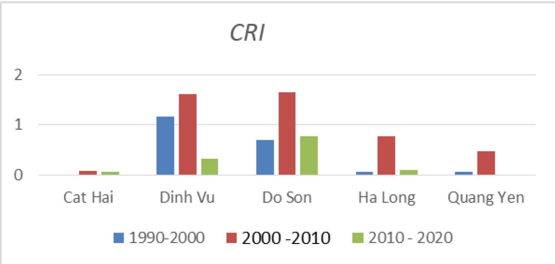

Figure 5. Coastal reclamation intensity in Hai Phong - Ha Long coastal area from 1990 to 2020

The CRI was calculated for each area over 1990–2000, 2000–2010, and 2010–2020 according to equation (1). During 1990–2000, the intensity of sea reclamation in the area was relartively low, ranging from 0 to 1.16 ha/km of coastline per year. The intensity of coastal reclamation in the Dinh Vu area was 1.16 ha/km of coastline per year, while in the Do Son, Ha Long, and Quang Yen areas, it was 0.7, 0.06, and 0.07 ha/km of coastline per year, respectively. During 2000–2010, the intensity of coastal reclamation in these areas ranged from 0.08 ha/km to 1.64 ha/km of coastline per year. The Cat Hai island area had the lowest reclamation intensity, while the Do Son area had the highest. From 2010 to 2020, the Do Son area continued to have the fastest rate of coastal reclamation compared to the other areas, with a CRI index of 0.77 ha/km of coastline per year, while the other areas had an index ranging from 0 to 0.32 ha/km per year (Fig. 5).

DISCUSSION

Coastal reclamation concerning socio-economic development in the period of 1990–2020

Coastal reclamation is a long-standing tradition of the Vietnamese people. In the 15th century, the Lê Dynasty encouraged coastal reclamation projects, forming many new villages in Quang Ninh, Nam Dinh, and Thai Binh provinces. Especially during the Nguyen Dynasty, coastal reclamation became a national policy. After the reunification of the country in 1975, coastal reclamation, exploitation of alluvial grounds, land protection, and coastal erosion prevention received even more attention, particularly during the renovation period since 1986. Hai Phong and Quang Ninh are two pivotal points in the socio-economic development triangle of Northern Vietnam. Coastal reclamation activities are occurring vigorously in these areas, which are closely linked with the socio-economic development of the two provinces. From 1990 to 2020, the area of coastal reclamation in the study area has been increasing over the evaluation periods, with different purposes observed for reclamation at each stage. During 1990–2000, the primary purpose of reclamation was to support aquaculture activities, driven by the government's policy of promoting shrimp farming for export. Many mangrove areas were cleared and converted into shrimp ponds during this period.

Additionally, the country’s economy embarked on a period of innovation, with agricultural development remaining a key focus. Consequently, activities such as constructing dikes and building dams to support aquaculture occurred in the study area. The mangrove forests suffered a loss of 281 hectares due to shrimp farming activities in Hai Phong from 1989 to 2001 [24]. Furthermore, mangrove planting projects, such as the Red Cross' PAM 5325 planting and initiatives, commenced in the Do Son and Tien Lang coastal areas (Hai Phong) in 1992.

From 2000 to 2010, the primary activities in the study area were coastal reclamation for aquaculture and mangrove planting. The mangrove forests in the Do Son and Tien Lang areas notably expanded during this time due to human efforts and the favorable development of alluvial flats. The formation and development of alluvial flats in this region are mainly driven by river dynamics, including current, sediment transport, and deposition, along with marine influences that shape estuary islands and coastal bars. These processes, along with ongoing estuarine sedimentation and tidal actions, contribute to the creation and elevation of tidal flats [14]. The well-developed mangrove forests have directly benefited the local community and Hai Phong City by increasing the productivity of natural seafood catch and reducing the cost of maintaining and protecting the city's embankments. Additionally, mangrove forests play a crucial role in coastal and dyke protection along this coastline [24].

From 2010 to 2020, land reclamation witnessed a significant surge in land reclamation projects in creating space for industrial zones and infrastructure to boost tourism development. During this time, several large-scale coastal reclamation projects were undertaken. Notable examples include the South Dinh Vu Industrial Zone project (part of the Dinh Vu - Cat Hai Economic Zone) covering 1,329.1 ha. Additionally, the DEEP C industrial park, spanning 513.4 ha, was established on the tidal marsh area of Dinh Vu Island. The Dragon Hill International tourist area, covering about 480 ha, was entirely formed through sea reclamation. Other projects include the Ha Long Marina urban area project covering 248 ha, the Tuan Chau - Ha Long resort on the Southeast coast of Tuan Chau Island, Tuan Chau ward, Ha Long city (Quang Ninh), with a scale of over 1,000 ha, the Ocean Park project, and the Dieu Island project in Ha Long, all of which involve extensive coastal reclamation. Hai Phong and Quang Ninh are both vast sea surface areas, making coastal reclamation an attractive option for investors seeking to reduce project compensation costs compared to acquiring land from local communities. In addition, the value of reclaimed land typically increases significantly compared to its original value. Furthermore, it can be argued that the primary motivation behind sea reclamation activities is the economic benefits derived from the increased land value [11, 25].

The processes of accretion and erosion have coincided and intertwined along the coast from Hai Phong to the Ba Lat estuary due to natural processes and human activities [17]. However, coastal reclamation in the study area has significantly increased in speed and intensity in recent years. The rapid rate of coastal reclamation, exceeding the natural rate of accretion, has completely changed the shape of the shore and the structure of alluvial dispersion, causing uneven accumulation of alluvium along the coast. This contributes to an accelerated accretion in some areas but causes erosion in others [26].

The status and progress of coastal reclamation activities in the Hai Phong - Ha Long area are like those of some coastal countries in Southeast Asia and Asia. The primary purpose of reclamation is to expand land and create space for socio-economic development [12, 27–29].

Policy implication

Despite its economic benefits, coastal reclamation can lead to problems such as the conversion of natural habitats to artificial ones, such as the transformation of mangroves into aquaculture ponds or coastal wetlands into levelled land. The rapid rate of coastal reclamation can alter natural conditions, terrain, and landscapes, impacting the hydrodynamic regime of the area, altering coastal flows, causing sedimentation and landslides in neighboring areas, and resulting in bank erosion, rendering structures unsafe. Furthermore, coastal reclamation can significantly impact ecosystems, biodiversity, and marine resources, adversely affecting lives and livelihoods and leading to various social problems for local coastal residents. However, regulations on managing sea reclamation activities in Vietnam remain limited, resulting in the leveling of many important wetland areas for economic development purposes. There have been several projects that have violated the world natural heritage site of Ha Long Bay, such as the urban project in area 10B, Quang Hanh Ward (Quang Ninh), which has reclaimed 3.9 hectares within the buffer zone of the Ha Long Bay heritage site (https://thanhnien.vn/o-at-do-dat-lan-bien-vung-dem-vinh-ha-long-de-lam-khu-do-thi-185231104 151151712.htm). Therefore, to effectively manage coastal reclamation activities, strong regulations, and enforcement mechanisms are needed, including permitting processes, environmental impact assessments, and monitoring mechanisms to ensure compliance with environmental standards and sustainable development goals. Moreover, modern technologies (remote sensing, drones, and others) should be applied in monitoring coastal reclamation activities to promptly detect illegal reclamation or encroachment on important marine ecosystems [13]. Furthermore, implementing integrated coastal zone management is necessary for coastal areas to establish a comprehensive policy coordination mechanism among fields such as urban planning, fisheries management, agriculture, and tourism. This approach aims to promote sustainable development and preserve ecosystems.

CONCLUSION

Over the past 30 years (1990–2020), coastal reclamation activities have intensified in the Hai Phong - Ha Long area and have shown a tendency to increase. The reclaimed areas in 1990–2000, 2000–2010, and 2010–2020 are 900 ha; 3,161 ha, and 3,434 ha, respectively. The purposes of coastal reclamation have shifted over time: from 1990–2010, it primarily served aquaculture and mangrove planting, while from 2010–2020, it focused on creating land for industrial parks, urban areas, and tourism resorts. Coastal reclamation activities have replaced natural coastlines with artificial ones, leading to a 33.5% increase in artificial coastlines between 1990 and 2020.

While offering socio-economic benefits, coastal reclamation significantly alters the coastline by replacing natural shores with artificial ones and converting mangroves, tidal flats, and shallow waters into new land. To ensure these projects comply with environmental standards and sustainable development goals, it is crucial to develop appropriate policies and mechanisms. Additionally, integrated coastal zone management models should be promoted and implemented to enhance policy coordination across economic sectors.

Acknowledgements: The study was made available under the framework of the projects VAST.05.06/22–23 and NVCC 23.01/24–25 funded by the Vietnam Academy of Science and Technology (VAST).

REFERENCES

[1] D. Sengupta, Y. R. Choi, B. Tian, S. Brown, M. Meadows, C. R. Hackney, A. Banerjee, Y. Li, R. Chen, and Y. Zhou, "Mapping 21st century global coastal land reclamation," *Earth's Future*, vol. 11, no. 2, 2023. DOI: 10.1029/2022EF002927.

[2] OSPAR Commission, *Assessment of the environmental impact of land reclamation*, *Biological Diversity of OSPAR Commission*, Publication No. 368/2008, 35 p., 2008.

[3] S. Y. Chee, M. L. Tan, Y. L. Tew, Y. K. Sim, J. C. Yee, and A. K. M. Chong, "Between the devil and the deep blue sea: Trends, drivers, and impacts of coastal reclamation in Malaysia and way forward," *Science of the Total Environment*, vol. 858, p. 159889, 2023. DOI: 10.1016/j.scitotenv.2022.159889.

[4] R. Glaser, P. Haberzettl, and R. P. D. Walsh, "Land reclamation in Singapore, Hong Kong and Macau," *GeoJournal*, vol. 24, pp. 365–373, 1991. DOI: 10.1007/BF00578258.

[5] N. H. M. Ghazali, "Coastal erosion and reclamation in Malaysia," *Aquatic Ecosystem Health & Management*, vol. 9,

no. 2, pp. 237–247, 2006. DOI: 10.1080/14634980600721474.

[6] M. Martín-Antón, V. Negro, J. M. del Campo, J. S. López-Gutiérrez, and M. D. Esteban, "Review of coastal land reclamation situation in the world," *Journal of Coastal Research*, vol. 75, pp. 667–671, 2016. DOI: 10.2112/SI75-133.1.

[7] W. Chen, D. Wang, Y. Huang, L. Chen, L. Zhang, X. Wei, M. Sang, F. Wang, J. Liu, and B. Hu, "Monitoring and analysis of coastal reclamation from 1995–2015 in Tianjin Binhai New Area, China," *Scientific Reports*, vol. 7, no. 1, p. 3850, 2017. DOI: 10.1038/s41598-017-04155-0.

[8] C. Xu, L. Pu, F. Kong, and B. Li, "Spatio-temporal change of land use in a coastal reclamation area: A complex network approach," *Sustainability*, vol. 13, no. 16, p. 8690, 2021. DOI: 10.3390/su13168690.

[9] W. Wu, M. Zhang, C. Chen, Z. Chen, H. Yang, and H. Su, "Coastal reclamation shaped narrower and steeper tidal flats in Fujian, China: Evidence from time-series satellite data," *Ocean & Coastal Management*, vol. 247, p. 106933, 2024. DOI: 10.1016/j.ocecoaman.2023.106933.

[10] H. Zhang, Y. Xiao, and Y. Deng, "Island ecosystem evaluation and sustainable development strategies: A case study of the Zhoushan Archipelago," *Global Ecology and Conservation*, vol. 28, p. e01603, 2021. DOI: 10.1016/j.gecco.2021.e01603.

[11] G. Yu, Y. Liao, Y. Liao, W. Zhao, Q. Chen, J. Kou, and X. Liu, "Research on integrated coastal zone management based on remote sensing: A case study of Guangxi Beibu gulf," *Regional Studies in Marine Science*, vol. 44, p. 101710, 2021. DOI: 10.1016/j.rsma.2021.101710.

[12] B. Tian, W. Wu, Z. Yang, and Y. Zhou, "Drivers, trends, and potential impacts of long-term coastal reclamation in China from 1985 to 2010," *Estuarine, Coastal and Shelf Science*, vol. 170, pp. 83–90, 2016. DOI: 10.1016/j.ecss.2016.01.006.

[13] F. Yan, X. Wang, C. Huang, J. Zhang, F. Su, Y. Zhao, and V. Lyne, "Sea reclamation in mainland China: process, pattern, and management," *Land Use Policy*, vol. 127, p. 106555, 2023. DOI: 10.1016/ j.landusepol.2023.106555.

[14] Nguyen Van Cu, *Coastal mudflats of Northern estuaries of Vietnam*. Hanoi: Publishing House for Science and Technology, 2006, 258 p. [in Vietnamese].

[15] T. H. Pham, K. N. Cuong, and V. U. Dinh, "Investigation of shoreline changes in the coast of Haiphong Province from 1987 to 2018," *VNU Journal of Science: Earth and Environmental Sciences*, vol. 37, no. 4, pp. 33–42, 2021. DOI: 10.25073/2588-1094/vnuees.4690. [in Vietnamese].

[16] T. V. Dien, T. D. Thanh, and N. V. Thao, "Remote sensing and GIS applications for monitoring coastal erosion in Red River Delta," *Collection of Marine Environment and Resources*, vol. 8, pp. 117–126, 2001. [in Vietnamese].

[17] N. V. Cu, N. T. Son, D. T. Thao, and N. H. Son, "Real changes of coastline from Hai Phong to Ninh Binh and exploitation of its resources," *Hue University Journal of Science (HU JOS)*, vol. 126, no. 7A, pp. 55–65, 2017. [in Vietnamese].

[18] E. Parwati, S. W. Adawiah, P. M. Afgatiani, and S. Budhiman, "TSS analysis using remote sensing data to detect reclamation activity in Jakarta Bay," *AIP Conference Proceedings*, vol. 2941, no. 1, 2023. DOI: 10.1063/5.0182603.

[19] V. H. Ha, T. T. Lien, N. T. Anh, N. C. Minh, and P. M. Duong, "The sea reclamation situation in Asian coastal city and experience lessons for Vietnam," *Vietnam Journals Online*, no. 3, 2022. [in Vietnamese].

[20] F. J. Aguilar, I. Fernandez-Luque, M. A. Aguilar, A. M. García Lorca, and A. R. Viciana, "The integration of multi-source remote sensing data for the modelling of shoreline change rates in a Mediterranean coastal sector," *International Journal of Remote Sensing*, vol. 40, no. 3, pp. 1148–1174, 2019. DOI: 10.1080/01431161.2018. 1524175.

[21] A. Misra and R. A. Balaji, "A study on the shoreline changes and land-use/land-cover using remote sensing and GIS along the

south Gujarat coastline, India," *Procedia Engineering*, vol. 116, pp. 381–389, 2015. DOI: 10.1016/j.proeng.2015.08.311.

[22] Y. Zhang, D. Li, C. Fan, H. Xu, and X. Hou, "Southeast Asia island coastline changes and driving forces from 1990 to 2015," *Ocean & Coastal Management*, vol. 215, p. 105967, 2021. DOI: 10.1016/ j.ocecoaman.2021.105967.

[23] B. Q. Dung and U. D. Khanh, "Calculation of Vietnam's coastline length (mainland) based on topographic map system at scale 1/50,000," *Vietnam Journal of Marine Science and Technology*, vol. 16, no. 3, pp. 221–227, 2016. DOI: 10.15625/1859-3097/16/3/8654. [in Vietnamese].

[24] T. D. Pham and K. Yoshino, "Mangrove mapping and change detection using multi-temporal Landsat imagery in Hai Phong city, Vietnam," in *The International Symposium on Cartography in Internet and Ubiquitous Environments 2015*, Tokyo, 17th–19th March, 2015, pp. 17–19.

[25] D. T. T. Huong, N. T. T. Ha, G. Do Khanh, N. Van Thanh, and L. Hens, "Sustainability assessment of coastal ecosystems: DPSIR analysis for beaches at the Northeast Coast of Vietnam," *Environment, Development and Sustainability*, vol. 24, no. 4, pp. 5032–5051, 2022. DOI: 10.1007/s10668-021-01648-x.

[26] T. D. Thanh, D. V. Huy, and T. D. Lan, "Development of the tidal flood plain in Red River Delta," *J. Sciences of the Earth*, vol. 3, no. 18, pp. 50–59, 1996.

[27] T. D. Thanh, D. V. Huy, and T. D. Lan, "Development of the tidal flood plain in Red River Delta," *Journal of Sciences of the Earth*, vol. 3, no. 18, pp. 50–59, 1996.

[28] K. Li, X. Liu, X. Zhao, and W. Guo, "Effects of reclamation projects on marine ecological environment in Tianjin Harbor Industrial Zone," *Procedia Environmental Sciences*, vol. 2, pp. 792–799, 2010. DOI: 10.1016/j.proenv.2010.10.090.

[29] D. Sengupta, R. Chen, and M. E. Meadows, "Building beyond land: An overview of coastal land reclamation in 16 global megacities," *Applied Geography*, vol. 90, pp. 229–238, 2018. DOI: 10.1016/j.apgeog.2017.12.015.