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Adverse Effects of Coastal Reclamation on the Environment and Ecosystems: A Case of Hai Phong—Ha Long Area (Vietnam)

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

Institute of Science and Technology for Energy and Environment (ISTEE), Vietnam Academy of Science and Technology (VAST), Hanoi 11300, Vietnam

ABSTRACT

The Hai Phong-Ha Long coastal area, with its World Natural Heritage site of Ha Long Bay-Cat Ba islands, has been under intense pressure from rapid development to meet the socio-economic goals set by Hai Phong City and Quang Ninh Province. As such, urgent land needs for infrastructure construction of economic sectors and urbanization have led to intensive coastal reclamation and seafill leveling, and their environmental consequences. The objective of this study is to assess the adverse environmental effects of coastal reclamation in the Hai Phong—Ha Long area, focusing on ecosystems, environmental quality, and seabed morphology at a regional scale. To achieve this objective, the study employed the regular techniques of environmental assessment methods, such as checklists, matrices, network diagrams, and overlay maps, to appraise these environmental consequences. The results show three main impacted natural components, including coastal ecosystems, environmental qualities, and morphological seabeds, besides coastline changes and socio-economic issues. The most impacted component was coastal ecosystems, followed by the coastal environmental qualities of seawater and sediments, and then the morphological seabed. Based on the study results, it is recommended that during the development

*CORRESPONDING AUTHOR:

Do Thi Thu Huong, Institute of Science and Technology for Energy and Environment (ISTEE), Vietnam Academy of Science and Technology (VAST), Hanoi 11300, Vietnam; Email: huongdt@istee.vast.vn; Tran Dinh Lan, Institute of Science and Technology for Energy and Environment (ISTEE), Vietnam Academy of Science and Technology (VAST), Hanoi 11300, Vietnam; Email: lantd@istee.vast.vn

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of an integrated coastal management plan for the coastal area of Hai Phong – Ha Long, environmental issues of coastal reclamation and seafill leveling must be given much attention.
Keywords: Coastal Reclamation; Environment Impact; Marine Ecosystem Degradation; Environmental Assessment; Seabed Morphology; Coastal Management; Sustainable Coastal Development

1. Introduction

Coastal reclamation, in general, and land leveling, in particular, are activities that have been ongoing throughout human history for hundreds of years, particularly in coastal countries globally [1], including Vietnam [2], to create more land for socio-economic development. Typical examples of coastal reclamation for industrial, agricultural, and urban development are countries such as Singapore, the Netherlands, Japan, Italy, India, China, the UK, or territories such as Hong Kong [3,4]. For countries and territories with limited land areas, the ratio of land area created from land reclamation to land area is very significant, as 5% in Hong Kong, 10% in Singapore, and up to 33% in Macao [5]. It is undeniable that land reclamation and sea leveling have brought great benefits to the development of coastal countries to meet the needs of developing residential areas, marine and coastal economic sectors, and industrial zones [6]. Over three decades, from the mid-1980s to 2017, a total of 1249.78 km^2 of land was reclaimed in 16 coastal megacities [7]. However, coastal land reclamation and sea level risealso cause negative impacts on the coastal environment, such as the deterioration of sediment and water quality, degradation or destruction of ecosystems, loss or reduction of biodiversity, changes in coastal hydrological regimes, coastal erosion, changes in coastal landscapes, and changes in seabed topography [1,8–13]. The negative impacts of land reclamation are particularly strong and obvious in coastal and island areas with economic and tourist development. Some studies in China show that the rate of land reclamation in Zhoushan Island reached 12.83 ± 0.17 m/year from 1970 to 2011 [14], which means that an equivalent area of natural habitats was lost per year; the Pearl River estuary was narrowed by 4km to 6km due to dyke construction for land reclamation in 5 years, 1974–1978 [15]. For 45 years (1980–2024), 47% of coastal wetlands were degraded due to land reclamation and sea level rise in Jiangsu [16]. Studies on monitoring and assessing the negative impacts of land reclamation and seafill leveling have been of interest for decades, especially when remote sensing technology and data are used to determine the area of land reclamation, the type of land reclamation, and the degree of spatial and temporal variation of the affected natural components [6,17–23].

The Hai Phong-Ha Long coastal area possesses internationally important natural conservation values recognized by UNESCO, such as the World Natural Heritage Site of Ha Long Bay-Cat Ba Archipelago (2023), Cat Ba Biosphere Reserve (2004), and is located in a dynamic development area with great potential for marine economic development. Therefore, land development needs are urgent for socio-economic activities such as seaport development [24], economic zones, coastal industrial parks, coastal urban areas, marine tourism infrastructure, etc. [23,25]. Land reclamation and seafill leveling have been taking place for a long time in this coastal area, but have been much intensive in the past 30 years (1990–2020), with the coastal land reclamation increasing rapidly, 900ha (1990–2000), 3,161ha (2000–2010), and 3,434ha (2010–2020) [25]. The environmental impacts of land reclamation and sea encroachment in this coastal area have only been assessed for each development project without integrated environmental impact assessments at the regional scale and over a long period. This study aims to comprehensively assess the environmental impacts of land reclamation and sea encroachment activities in the Hai Phong-Ha Long coastal area, to promote sustainable coastal management. The study outcomes will contribute to the development of plans and solutions for the rational use of resources and environmental protection, as well as nature conservation, in the coastal and marine areas of international importance, including the World Natural Heritage Site of Ha Long Bay - Cat Ba Archipelago and the Cat Ba Biosphere Reserve.

2. Materials and Methods

2.1. Study Area

Coastal Hai Phong – Ha Long encompasses two provincial municipalities of Hai Phong city and Quang Ninh province, which are designated by the Vietnam Government as part of the economic development triangle of Ha Noi - Hai Phong – Quang Ninh. The coastal area is very populated, with over 2.1 million people per 1,562.5 km² in Hai Phong (2024) and over 353 thousand individuals per 1,119.36 km² in Ha Long city (2024). Hai Phong coastal area receives fresh water and sediments from five river mouths (Lach Huyen, Cam, Lach Tray, Van Uc, and Thai Binh). Meanwhile, Ha Long Bay is supplied with fresh water and sediments from the very short rivers and temperate runoff in the rainy season. Key economic sectors include ports and maritime transport, tourism, coastal industrial zones, fisheries, coastal aquaculture, and agriculture. All these sectors have been rapidly and intensively developed seaward, particularly port and maritime transport associated with industrial zones, and tourism with urbanization and resorts. In the coming years, the land is urgently needed for infrastructural construction for socio-economic development. For instance, in the Hai Phong socio-economic development master plan for 2030 and the vision to 2050, land reclamation by seafill leveling is estimated at 251 million cubic meters in the period 2020–2030 and increasing afterward [26,27].

On the other hand, this coastal area possesses natural values of international importance, including the Ha Long Bay – Cat Ba islands Natural Heritage, Cat Ba Biosphere Reserve (**Figure 1**) with high biodiversity at coastal ecosystems of mangroves, seagrass beds, coral reefs, tidal flats, rocky reefs, saltwater lakes, and sandy beaches, and at species [27,28].

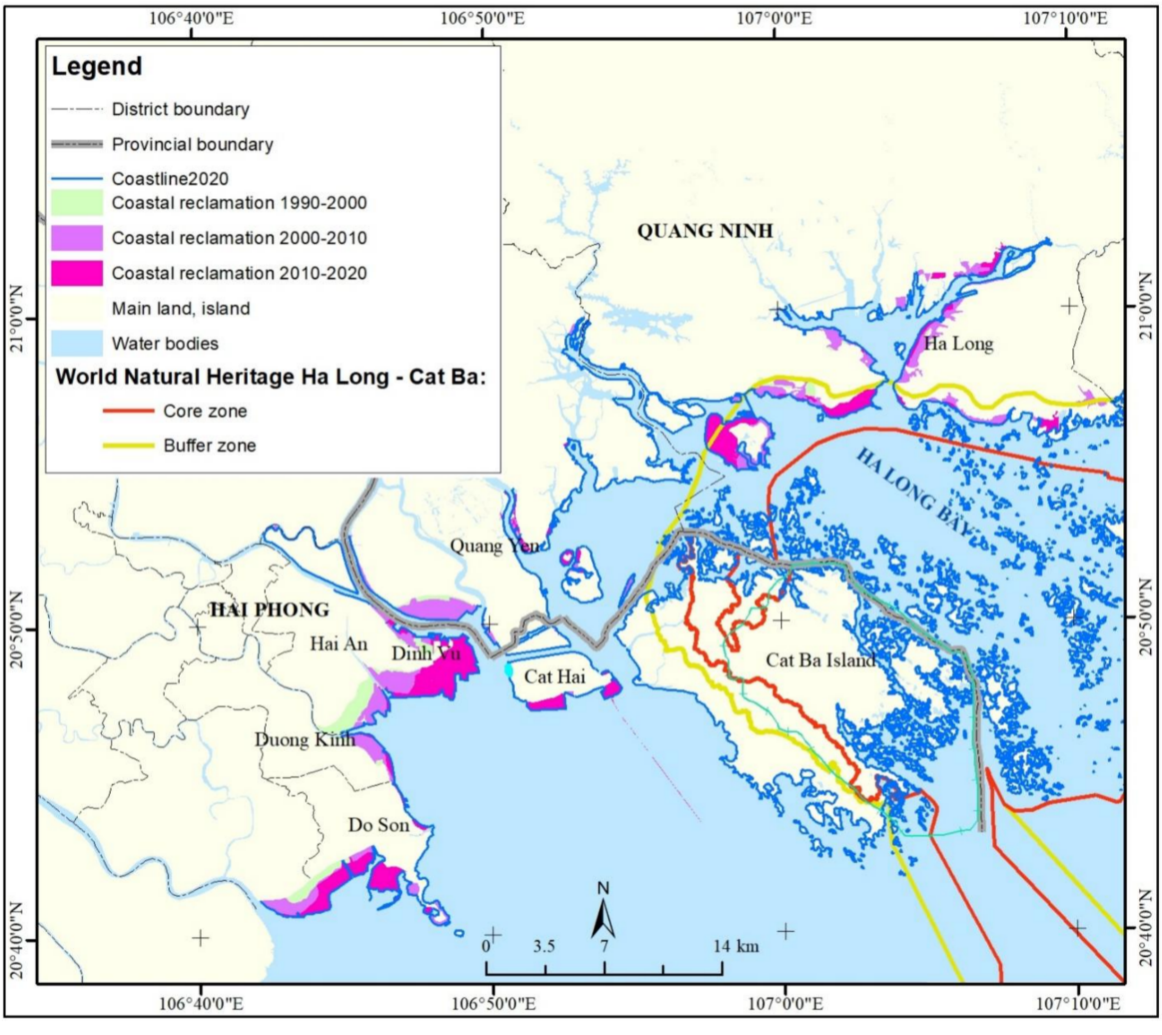

Figure 1. Study site and reclamation area (1990–2020).

Source: modified from Huong et al., 2025 [8].

2.2. Materials

Data for this study were collected mainly from the scientific projects VAST.05.06/22–23 and NVCC 23.01/24–25 funded by the Vietnam Academy of Science and Technology (VAST) and Project "Development of comprehensive solutions for environmental management in the northeast coastal waters of Viet Nam in an age of global changes" coded NDT/ITA/2024/07 implemented during the period 2022–2023 and 2024–2025, respectively.

Data on environmental quality were collected from 8 survey transects in Hai Phong and Ha Long from 2010 to 2022, with environmental parameters of DO, COD, BOD, NH_4^+, NO_3^-, PO_4^{3-}, and TSS. Data on seabed morphology were from surveys in 2022–2023. Ecosystem materials were collected from surveys in 2023–2025.

Apart from the surveyed and investigated primary data, study materials were collected from relevant project reports, statistical books, and publications. Socio-economic data from time series in statistical yearbooks of Hai Phong and Quang Ninh were used for environmental assessment.

2.3. Methods

The study applied a combination of qualitative, semi-quantitative, and quantitative approaches, including rapid appraisal, assessing matrix, cause–and–effect analysis, environmental impact measurement (EIM), and field surveys.

Rapid appraisal is a qualitative, field-based method used to quickly gather environmental information in situations where time, resources, or data are limited. It emphasizes participatory techniques, local knowledge, and observational tools to identify environmental risks and priorities [29]. In this study, checklist and ranking matrices techniques were employed to identify the environmental problems raised and their impacts by coastal reclamation and land leveling in the region.

The assessing matrix method—often referred to as an interaction matrix—is a semi-quantitative tool used to evaluate the environmental impacts of a project by systematically identifying the relationships between project activities and environmental components [30,31]. The interaction matrix was used to identify direct and indirect impacts of reclamation and infilling on ecosystems, the water environment, and seabed morphology in the region. The interaction matrices were formed by reclamation and infilling activities, and their characteristics in each area of the region of Hai Phong – Ha Long versus the ecological and environmental features of each area. The matrix was also adapted into weighted matrices for more detailed scoring with the contributions from 15 environmental and ecological experts.

Cause–and–effect analysis is a structured problem-solving technique used to identify the root causes of the environmental and ecological impacts of coastal reclamation on ecosystems and environmental quality in the region. Five steps were applied, including defining the problem (effect), identifying major categories, brainstorming possible causes under each category, adding sub-causes, and analyzing the diagram to find root causes. The technique was carried out by the study team in consultation with 15 experts in the fields of environmental and ecological research and management.

To complement these qualitative and semi-quantitative methods, an Environmental Impact Measurement (EIM) framework was applied to quantify and classify the level of environmental impacts caused by coastal reclamation. The EIM system assigns weighted scores to three major impact categories: (i) coastal ecosystems, (ii) water quality, and (iii) seabed morphology. The category score was carried out in consultation with 15 experts in marine ecology and environmental management. Weighted matrices were used to combine expert judgments and measured parameters, ensuring that both scientific data and professional knowledge contributed to the evaluation.

For each category, specific indicators/parameters were quantified, including area of ecosystem loss (ha), deviations of water quality indicators (DO, BOD_5, COD, NO_3^-, NH_4^+, PO_4^{3-}) from national standards (QCVN 10-MT:2022/BTNMT), and changes in erosion–accretion rates. All indicators were normalized to a 0–100 scale using a standard min–max linear transformation method, following OECD (2008) and subsequent ecological assessment studies [32,33]. Threshold-based classification was applied using the IUCN Red List of Ecosystems guidelines [34] for coastal ecosystems and QCVN thresholds for water quality.

Scores were then classified into three levels: Low (0–33), Medium (34–66), and High (> 66), consistent with EIM applications in environmental impact assessments [30,35].

Field surveys were implemented in 2022–2023, obtaining complementary environmental and ecological quality parameters and seabed morphological transformation in the region. Water quality data were obtained from 8 survey transects across the Hai Phong – Ha Long coastal zone, including Do Son, Cat Hai, Dinh Vu, Cua Luc, Tuan Chau, and Bai Chay. Measurements were taken seasonally (dry and rainy seasons). Environmental parameters (DO, COD, BOD, NH_4^+, NO_3^-, and PO_4^{3-}) were measured following Vietnamese standard methods. Specifically, DO was measured using a DO meter (electrochemical method), and BOD by the 5-day BOD test. COD was determined by oxidation using Potassium Permanganate ($KMnO_4$) in an alkaline medium. PO_4^{3-} , NO_{2-}, and NH_4^+ were determined by a colourimetric method. Seabed morphology was observed and measured with side-scan sonar and bathymetric data.

3. Results

3.1. Coastal Reclamation Characteristics and Affected Components in the Hai Phong – Ha Long Coastal Area

Coastal reclamation has taken place in Hai Phong city with the largest single conversion project of 22,500 ha for the economic zone of Dinh Vu – Cat Hai (industrial areas included). Three mainly natural coastal ecosystems of mangroves, seagrasses, and tidal flats were converted to artificial structures of seaport facilities, logistic companies, and other maritime-related industries. At the smaller-scale conversions (e.g., 50–720 ha), tourism and urbanization in both cities of Hai Phong and Ha Long have occupied areas of natural ecosystems of beaches, tidal flats, and marine soft bottom.

Hai Phong has also made its efforts in restoring coastal sensitive ecosystems with one initiative noted as ecological restoration of mangrove replanting (https://en.vietnamplus.vn/millions-in-coastal-areas-benefit-from-mangrove-forest-post86245.vnp) (**Table 1**).

Materials used for land leveling in coastal areas are mainly medium to fine-grained sand from coastal shoals. In addition, hilly and mountainous soil materials are also used. In Hai Phong, dredged materials from shipping channels and seaports after being treated to separate clay are also used for land leveling for industrial parks in Dinh Vu (https://mt.gov.vn/mkhcn/Pages/ChiTietTin.aspx?groupID=997&IDNews=85092). In the Ha Long area, in addition to sand and hilly soil materials, solid waste from open-pit coal mines is also used for land leveling in some coastal places. The quality parameters of these materials that affect the water quality in the study area are mainly related to the fine-grained composition of sediments, organic matter content, heavy metals, and nutrients. Sand materials used for land leveling in the Hai Phong - Ha Long coastal area all have environmental quality parameters similar to those of the sediments in the area because they are exploited in nearby coastal shoals [27]. The content of fine particles (<0.063 mm) in sand in Hai Phong is usually < 30%, while in Quang Ninh, the content of these particles is negligible. Other environmental quality parameters are within the permissible limits of Vietnam [24,27]. Hilly soil is rarely used and all ensure material quality except for the content of clay particles, which is often high. In particular, waste from stripping seams in open-pit coal mines in Ha Long, Quang Ninh, contains some pollutants such as heavy metals (lead, cadmium, mercury), which can cause water environmental pollution (https://vinatro.com.vn/danh-gia-tac-dong-moi-truong-cua-cac-mo-than-o-viet-nam/), so its use is very limited.

Table 1. Natural ecosystem conversion to artificial structures in Hai Phong – Ha Long coastal areas.

Province/City	Artificial Structure	Nature Converted	Square Area Converted (ha)	Remark
Hai Phong city	Economic zone (industrial areas included)	Ecosystems of mangroves, seagrasses, and tidal flats	22.500	Dinh Vu – Cat Hai Economic Zone
Hai Phong city	Tourism development (tourist resorts, tourist facilities, etc.)	Ecosystems of tidal flats and beaches	643	Do Son district
Hai Phong city	Tourism and urbanization (tourist resorts, new residential areas)	Beaches and marine soft bottoms	50	Cat Ba islands
Hai Phong city	Mangrove replanting	Tidal flats	965.23	Districts of Do Son, Kien Thuy, and Tien Lang
Ha Long city (Quang Ninh province)	Tourism and urbanization (tourist resorts, new residential areas)	Tidal flats, beaches, and marine soft bottoms	720	Areas of Bai Chay, Tuan Chau
Ha Long city (Quang Ninh province)	Urbanization (new residential areas, roads, and other urban infrastructures	Tidal flats, mangrove, and marine soft bottoms	1511.4	Along the coast of Ha Long city

Source: Projects VAST.05.06/22–23 and NVCC 23.01/24–25.

3.2. Impacts on Coastal Ecosystems

Based on the cause–and–effect analysis, reclamation and infilling were identified as the primary drivers leading to the direct conversion of mangroves, tidal flats, seagrasses, and shallow coastal waters into industrial, urban, and tourism land uses. Among the seven coastal ecosystems mentioned in the Hai Phong-Ha Long area, four of them (excluding marine soft bottom) are under the impacts of sea reclamation, including the sensitive ecosystems of mangroves, seagrasses, tidal flats, and beaches.

From 2000 to 2020, numerous tidal wetland ecosystems in the Hai Phong – Ha Long region were converted into industrial zones, tourist areas, and new urban areas. For example, the mangrove forest area on Dinh Vu Island was transformed into an industrial park, while shallow coastal waters in Do Son and Ha Long were turned into urban and tourism land. Specifically, from 1990 through 2000, 128 ha of tidal flat ecosystems were converted into aquaculture zones; 97 ha of mangrove forests were turned into urban, industrial, and tourism land. Between 2000 and 2010, 1,210 ha of tidal flats and 70 ha of mangroves were converted into aquaculture ponds; 859 ha of tidal flats, 66 ha of mangroves, and 406 ha of shallow coastal waters were turned into urban areas; and 129 ha of tidal flats were converted to industrial land. From 2010 to 2020, approximately 2932 ha of shallow coastal waters, 1,327 ha of tidal flats, and 30 ha of mangroves were infilled and transformed into land for socio-economic development; around 37 ha of tidal flats and 5.5 ha of mangrove forests were converted into aquaculture zones (**Table 2**).

A positive action in the period from 2000 to 2020 was the restoration of mangrove ecosystems, with 664 ha of mangroves reforested through plantation projects in Do Son and Tien Lang (Hai Phong).

Table 2. Conversion of tidal wetland ecosystems due to infilling & reclamation (Hai Phong – Ha Long, 1990–2020).

Ecosystem Type	1990–2000 (ha)	2000–2010 (ha)	2010–2020 (ha)	Total (ha)
Tidal flats → Aquaculture	128	1210	37	1375.0
Mangroves → Aquaculture	97	70	5.5	172.5
Tidal flats → Urban/Industrial land	–	859	1327	2186.0
Mangroves → Urban/Industrial land	–	66	30	96.0
Shallow coastal waters → Urban/Industrial land	–	406	2,932	3338.0
Total				**7167.5**

Source: Projects VAST.05.06/22–23 and NVCC 23.01/24–25.

Table 2 provides quantitative data on the conversion of tidal flats, mangroves, and shallow coastal waters into aquaculture, urban, and industrial land between 1990 and 2020. To complement these statistics, **Figure 2** illustrates the spatial distribution of such ecosystem changes across the Hai Phong – Ha Long coastal area. The combination of tabular data and spatial mapping highlights not only the scale of ecosystem loss but also its geographic concentration in sensitive zones such as Dinh Vu–Cat Hai, Do Son, Bai Chay, and Tuan Chau. This integrated presentation underscores the extent to which reclamation has reshaped the coastal ecosystems of the study area.

3.3. Impacts on the Environmental Quality of Coastal Water

To assess the impact of land reclamation on coastal environmental quality, correlations between reclamation rates and environmental quality indicators were analyzed. Assessment parameters included DO, COD, BOD_5, NO_3^-, NH_4^+, and PO_4^{3-}. Comparisons were made before and after reclamation activities during the dry season, rainy season, and two transitional seasons.

3.3.1. Impact on Water Environment in Hai Phong – Ha Long during the Dry Season

After land reclamation, the DO average concentration is generally higher across most areas. In contrast, a slight lowering was observed in the Cua Luc embayment. Average BOD_5 levels rose throughout the region. COD also showed an overall increase, except for a decrease along the Bai Chay coastline. The average concentrations of NO_3^-, NH_4^+, and PO_4^{3-} all got higher across the entire region (**Figure 3**).

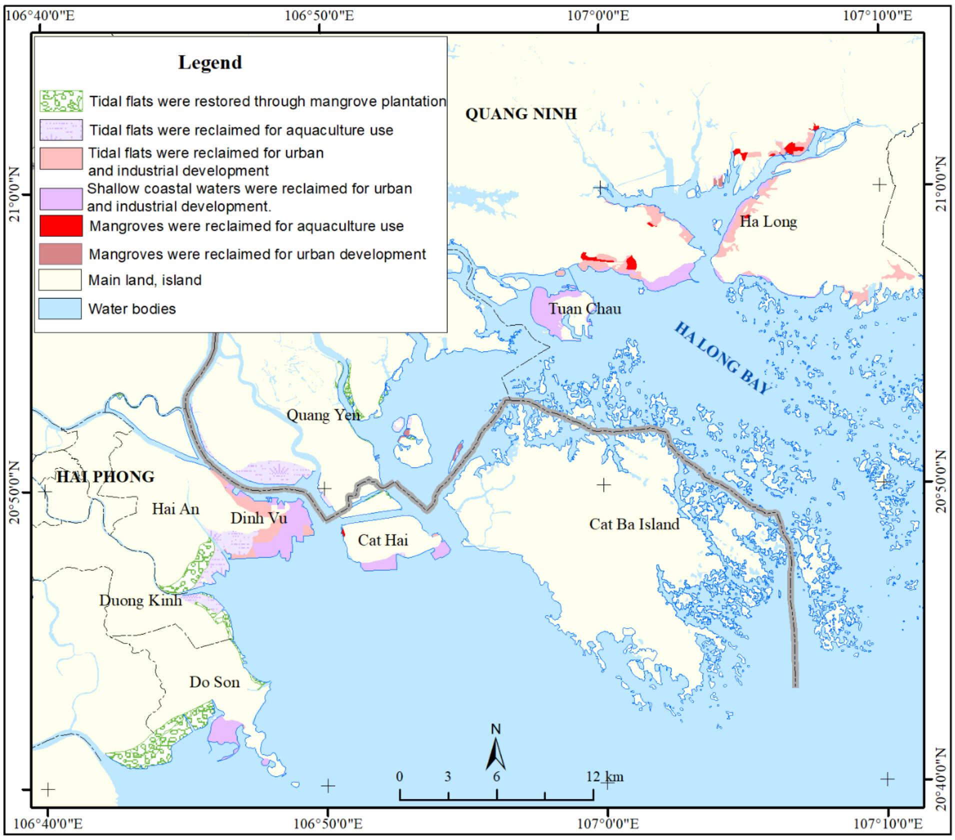

Figure 2. Map of coastal ecosystem changes caused by reclamation activities (1990–2020).

Source: Projects VAST.05.06/22–23 and NVCC 23.01/24–25.

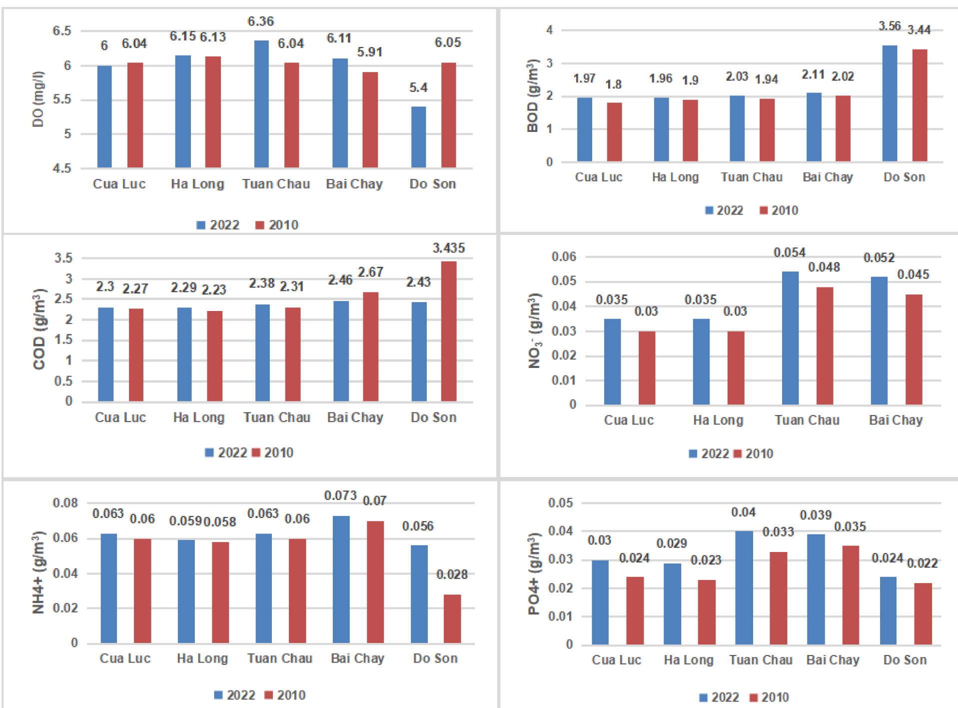

Figure 3. Changes in average water quality parameters in Ha Long Bay during the dry season—before (2010) and after reclamation (2022).

Source: Projects VAST.05.06/22–23.

3.3.2. Impact on Water Environment during the Rainy Season

Average DO concentrations were higher than those before reclamation in Don Son, Cua Luc embayment, and central Ha Long Bay, with minimal change along coastal Bai Chay. Conversely, DO was low in Do Son, the southern area of Tuan Chau Island. Average BOD_5 rose in Do Son, central Ha Long Bay, and Bai Chay, but declined in the Cua Luc Bay entrance and southern Tuan Chau Island. Average COD values decreased in Do Son, Cua Luc Bay, and Bai Chay, with insignificant changes in central Ha Long Bay. NO_3^- concentrations dropped in Cua Luc embayment and southern Tuan Chau, with slight growth in central Ha Long Bay and Bai Chay. NH_4^+ was small in southern Tuan Chau but rose in central Ha Long Bay and remained stable in Cua Luc embayment. PO_4^{3-} got bigger in all areas (**Figure 4**).

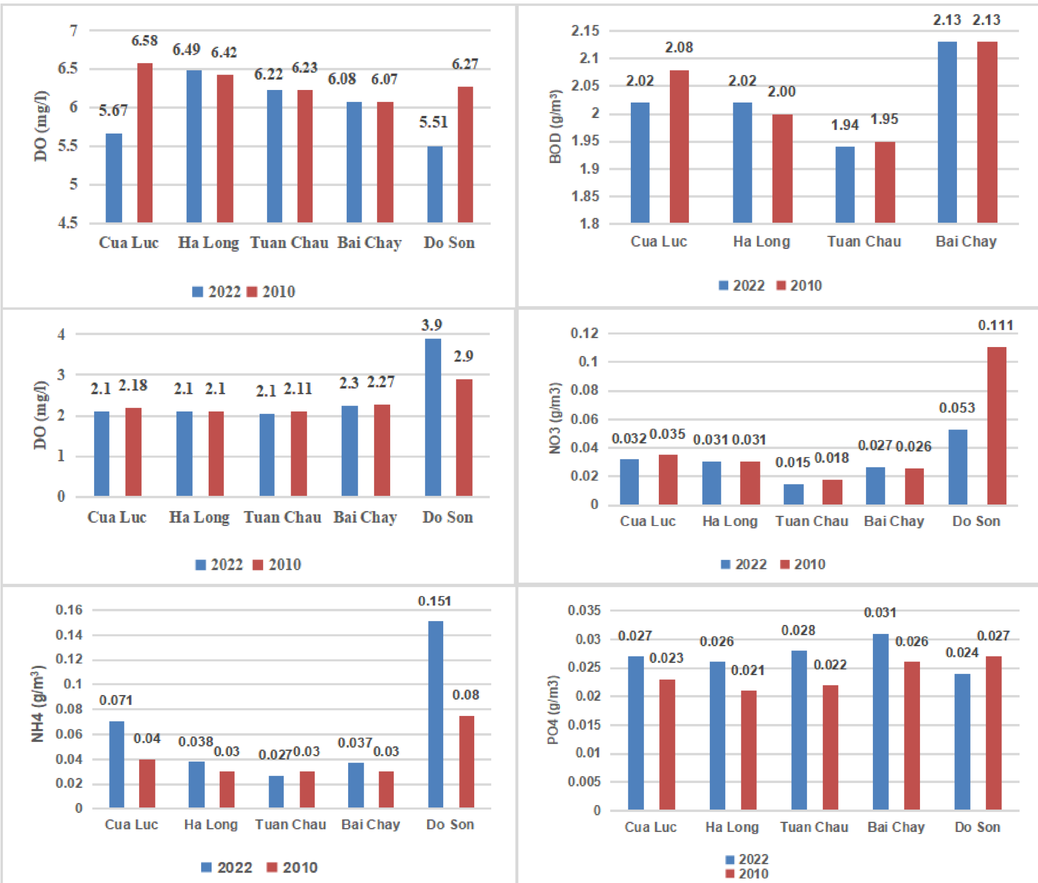

Figure 4. Changes in average water parameters in Ha Long Bay during the rainy season before and after reclamation.

Source: Projects VAST.05.06/22–23.

3.3.3. Impact during the Dry-to-Rainy Season Transition

After reclamation, DO levels were higher in Cua Luc embayment and central Ha Long, but lower in southern Tuan Chau and Bai Chay. Fluctuations in BOD_5 and COD concentrations were unclear. BOD_5 rose in southern Tuan Chau and Bai Chay, but declined in Cua Luc embayment and central Ha Long Bay. COD got higher in southern Tuan Chau. NO_3^- levels dropped in Cua Luc embayment and central Ha Long, but rose in Bai Chay and southern Tuan Chau. NH_4^+ declined across all areas. PO_4^{3-} fell throughout the region, except for a slight growth in southern Tuan Chau (**Figure 5**).

3.3.4. Impact during the Rainy-to-Dry Season Transition

In post-reclamation, average DO concentrations rose throughout the entire region. Average BOD_5 and COD levels also rose. NO_3^- concentrations declined in Cua Luc embayment but showed slight growth elsewhere. Both NH_4^+ and PO_4^{3-} average concentrations got higher across the region.

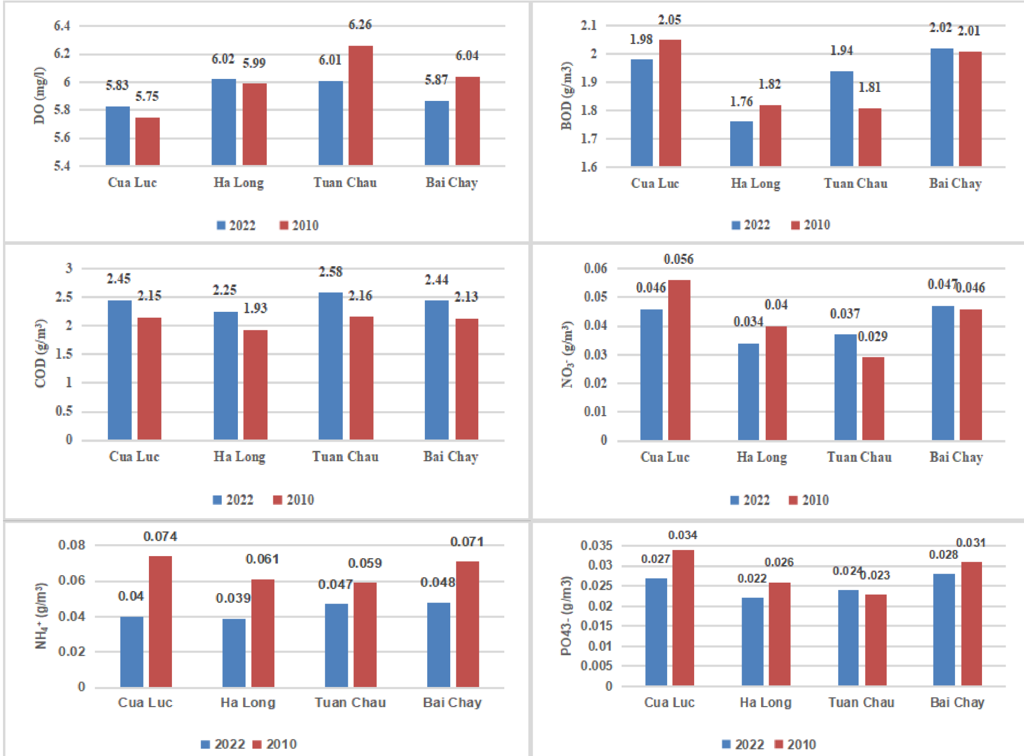

Figure 5. Changes in average water parameters in Ha Long Bay during the dry-to-rainy transition season.

Source: Projects VAST.05.06/22–23.

3.3.5. Impacts on Morphological Seabeds

Land reclamation activities have demonstrated clear environmental impacts by altering suspended sediment concentrations (SSC) and erosion-accretion dynamics.

After reclamation, high SSC was observed in the northern area of Tuan Chau Island. SSC slight growth also occurred along the coast of the region. In contrast, SSC got lower in areas from the southern Cua Cam–Nam Trieu region down to the northeastern tip of Do Son Peninsula. Offshore areas showed minimal change from reclamation activities on SSC (**Table 3**).

Table 3. Seasonal fluctuations in SSC in the Hai Phong – Ha Long coastal region.

Season	SSC Change
Dry Season	Increased by 0.12–0.39 g/m³
Dry → Rain Transition	Decreased by 0.01–0.9 g/m³ (except a rise of 1.46 g/m³ in south Tuan Chau)
Rainy Season	Decreased by 0.43–0.85 g/m³
Rain → Dry Transition	Increased by 0.02–0.82 g/m³

Source: Projects VAST.05.06/22–23.

Field observations and modeling of hydrodynamic responses in the Hai Phong – Ha Long coastal area indicate significant alterations in sediment transport patterns following reclamation activities. For instance, a numerical model by Nguyen Minh Hai et al. (2019) documented changes in suspended sediment concentration and morphological deformation in key coastal sectors, attributing these shifts to intensified currents and reduced sediment supply around reclamation zones [36]. Similarly, a hydrodynamic simulation in Cat Hai Island—located within the Hai Phong region—revealed notable increases in flow magnitude and directional shifts due to shoreline modifications, indicating that embankment structures may accelerate localized erosion [37]. Based on these findings, it is reasonable to infer accelerated erosion near river mouths and increased deposition in semi-enclosed bays following reclamation-induced hydrodynamic changes in the region.

3.3.6. EIM Scoring of Reclamation Impacts

Based on data for three impact categories collected in 2022, together with pre-reclamation baselines (1990 for coastal ecosystems and 2010 for water quality) and expert-assigned weights, EIM scores were calculated for the Hai Phong–Ha Long region. Scores were normalized against these baselines. Thresholds for water quality followed the permissible limits defined in the Vietnamese standard for coastal seawater quality (QCVN 10:2023) and ASEAN guidelines for parameters not specified in Vietnamese regulations. For ecosystem indicators, thresholds were adapted from international guidelines [32], while references from regional case studies were additionally used to establish thresholds for seabed morphology.

The weighted overall impact measure was calculated by combining the three category scores using expert-assigned weights: Ecosystem (0.40), Water quality (0.25), and Seabed morphology (0.35). The resulting overall impact measure score was 52.9, corresponding to a medium impact level (**Table 4**). This reflects the dominant contribution of ecosystem loss (61.7) and seabed morphological alteration (60.0), which together outweigh the relatively low score for water quality deterioration (28.9). Overall, the results indicate that reclamation-induced impacts are most pronounced in ecological and morphological domains.

Table 4. EIM scoring of reclamation impacts.

Impact Category	Indicators/Parameters	EIM score	Impact Level
Coastal ecosystem	Area of mangroves and tidal flats converted	61.7	Medium – high
Water quality	DO, BOD_5, COD, NH_4^+, NO_3^-, PO_4^{3-}, TSS deviations from QCVN 10:2023	28.9	Low
Seabed morphology	Erosion rate	60	Medium – high
Overall	Weighted sum (Ecosystem 0.4; Water 0.25; Morphology 0.35)	52.9	Medium

4. Discussion

The two municipalities of Hai Phong and Ha Long have been experiencing intense urban and tourism-driven land use changes, particularly in coastal areas. Most development projects are often located in ecologically vulnerable zones such as Cat Ba islands, Do Son, Tuan Chau, and Bai Chay—all known for tourism and biodiversity. Development activities lead to the increasing infilling and reclamation in this coastal area. Consequently, negative environmental impacts from coastal infilling and reclamation on coastal ecosystems become serious.

The direct impact of land reclamation activities on coastal ecosystems in the Hai Phong – Ha Long coastal region is the conversion of natural wetlands into artificial wetlands or their complete loss. Most coastal reclaimed and infilled areas around the world were under this impact. In coastal Jiangsu (China), 2931.54 km^2 of natural wetlands were shifted to constructed land or aquaculture and agricultural cultivation over the last 45 years, 1980–2024 [16]. Also, in the Guangdong–Hong Kong–Macao Greater Bay Area, mangrove cover declined by 45 % (≈ 11.7 km^2) between 1985 and 2015, largely attributed to urban expansion and aquaculture pond conversion [38]. In Malaysia, coastal reclamation destroyed natural habitats by 17 % [11]. The extent of coastal land reclamation in Dammam Metropolitan Area along the eastern coast of Saudi Arabia experienced between 66.5% and 100% of their total water surface and marine vegetation reclaimed within the last two decades, 2000–2020 [10].

The natural wetland conversion by coastal reclamation leads to further effects on marine species, biodiversity, and the overall marine environment recorded in Malaysia [1] and China [20,39,40]. Regularly, the spawning and nursery grounds for fish and crustaceans are found in shallow coastal waters or estuaries [41,42]. Unfortunately, most reclamation and infilling activities in the coastal areas of Hai Phong – Ha Long have occurred in precisely these locations.

The indirect consequence of land reclamation is the depletion of natural capital [43–45]. Based on previous studies [46,47], the economic value lost when marine ecosystems are degraded can be estimated. The total economic value per hectare of the coastal ecosystem per year is USD 359,054.58, equivalent to roughly 8.6 billion VND [46]. Therefore, converting 7167.5 ha of wetlands (including tidal flats, mangroves, and shallow coastal waters) into urban, industrial, and aquaculture land from 1990 to 2020 results in an annual loss of approximately 61,640.5 billion VND.

There is also a clear relationship between shoreline modification (including infilling and reclamation) and the decline of natural fisheries in major fishing grounds [48].

Large-scale reclamation projects alter the hydrodynamics of nearshore waters and affect the migration patterns of marine species [49]. These changes are detrimental to marine productivity and the sustainable development of fishery resources [45,50]. Moreover, high concentrations of suspended solids generated during reclamation processes may severely affect fish eggs, larvae, and coral species [51–53]. The mass coral bleaching events observed in Cat Ba - Ha Long are associated with increased water turbidity [54]. Although quantitative data on resource degradation due to reclamation are currently lacking, local interviews in Do Son indicate that the opening of the Dragon Hill tourism project has led to a decline in crustacean species (e.g., fiddler crabs, ghost crabs) caught by locals, due to large areas of tidal flats being converted into tourism and resort facilities.

Adverse effects are also on the coastal water quality [55]. Water quality indicators of organic (BOD_5, COD) and nutrient (NO_3^-, NH_4^+, and PO_4^{3-}) pollutions show the increasing pollution trend after reclamation and infill in the Hai Phong – Ha Long coastal region. The increase takes place in most areas in the dry season (November to March) and the transitional month from rainy to dry seasons (October). In the rainy season (May to September) and the transitional month from dry to rainy seasons (April), the dynamics of these indicators are complicated (increasing and decreasing in different areas) (**Table 5**). This may be caused by the interference of the river flows and runoffs contributing different volumes of fresh water and other environmental parameters to different areas in the region [56,57]. In the region with four distinct seasons, such as Hai Phong – Ha Long. Adverse impacts of the coastal development activities are often expressed in the dry season [58,59]. Although the negative impacts on coastal water quality also come from other development activities, coastal reclamation and infill contribute partly to the decrease in water quality.

Table 5. Water Quality Changes Across Seasons (Before and After Reclamation).

Indicator	Dry Season	Rainy Season	Dry→Rain Transition	Rain→Dry Transition
DO	↑ most areas, ↓ at Cua Luc Bay	↑ Cua Luc & central Ha Long; ↓ south Tuan Chau	↑ Cua Luc & central Ha Long; ↓ Bai Chay & south Tuan Chau	↑ across all areas
BOD_5	↑ all areas	↑ central Ha Long & Bai Chay; ↓ Cua Luc & south Tuan Chau	↑ Bai Chay & south Tuan Chau; ↓ Cua Luc & central Ha Long	↑ all areas
COD	↑ all areas; ↓ Bai Chay	↓ Cua Luc & Bai Chay; ↔ central Ha Long	↑ South Tuan Chau; unclear elsewhere	↑ all areas
NO_3^-	↑ all areas	↓ Cua Luc & south Tuan Chau; slight ↑ elsewhere	↓ Cua Luc & central Ha Long; ↑ Bai Chay & south Tuan Chau	↓ Cua Luc; slight ↑ elsewhere
NH_4^+	↑ all areas	↓ south Tuan Chau; ↑ central Ha Long; ↔ Cua Luc	↓ all areas	↑ all areas
PO_4^{3-}	↑ all areas	↑ all areas	↓ all areas except slightly ↑ in the south of Tuan Chau	↑ all areas

Note: ↑ = Increase; ↓ = Decrease; ↔ = No significant change.

Seabed morphology was also markedly altered. Bathymetric surveys revealed increased suspended sediment concentrations in areas adjacent to reclamation sites (Tuan Chau), and intensified erosion–accretion dynamics near Do Son and Cua Cam. These changes are directly linked to channel narrowing, hydrodynamic modifications, and the redistribution of dredged materials used in infilling. Such alterations not only reshape local sediment budgets but also reduce the resilience of benthic habitats. On North Tuan Chau Island, after land reclamation, the SSC increased due to changes in hydrodynamics, such as channel narrowing and reduced circulation resulting from infill. In contrast, the SSC decreased in the South of Cua Cam to the Northeast Do Son Peninsula area (Hai Phong). This can be caused by sediment dispersion due to high water flow discharged from the river mouths. On other coastal stretches, the SSC slightly increased, and in the offshore regions, it remained unchanged. It indicates that the coastal stretches and offshore regions are less affected by reclamation. Seabed erosion shows a decreasing trend in all areas where reclamation and infill took place. Meanwhile, increasing erosion in offshore regions is due to the lack of sediment discharge. Analyzing remotely sensed data from 1990 to 2020 for detecting coastal reclamation area in the region of Hai Phong – Ha Long showed the complicated changes in seabed morphology with erosional and depositional processes [25]. Similar situations were observed in other coastal areas. Coastal reclamation generated the current speeds higher in tidal creeks and lower in tidal flats, leading to the decrease of SSC concentration and deposition rates in the tidal flat in Rui'an coast of China [60], and similar cases of Taizhou Bay, East China [61], and Qinzhou Bay, Southwest China [62]. Using a geospatial data set for 500 years in Em's estuary (located at the border between Germany and the Netherlands) [58], it was indicated that the intertidal-subtidal area ratio altered due to land reclamation works and that the ratio partly restored after land reclamation ended in this estuary [63].

The EIM framework provides a transparent, target-based approach to translate multi-metric monitoring of ecosystems, water quality, and seabed morphology into management-ready impact classes (Low, Medium, High). This enables decision-makers to prioritize restoration in high-impact zones while strengthening monitoring and mitigation in medium-impact areas. Due to limited monitoring data, EIM is presented here as a methodological framework rather than a fully quantified index. Future studies should integrate long-term ecological datasets with socio-economic indicators to refine EIM scoring and support integrated coastal management. In parallel, Circular Economy (CE) principles offer strategies to reduce the ecological footprint of reclamation. These include reducing demand for virgin materials (reduce), reusing dredged sediments after proper treatment (reuse), recycling industrial by-products such as fly ash and construction waste (recycle), and recovering ecological functions through mangrove replanting and wetland restoration (recover). Indicators such as the proportion of recycled fill materials, reduction in waste to disposal, and hectares of restored wetlands could serve as CE-based metrics for future projects.

Another issue is waste management. Large-scale reclamation and industrial expansion generate significant amounts of dredged sediments and construction debris. Improper handling of these materials—especially contaminated dredged sediments—poses serious risks to marine environments. For example, dredged sediments in the Pearl River Estuary region have shown elevated levels of heavy metals (Cd, Hg, Pb, Cu), which, when improperly disposed of, degrade coastal water quality and benthic habitats [64]. Similarly, in the Hai Phong coastal area, heavy metal concentrations in surface sediments often exceed interim sediment quality guidelines, indicating significant pollution likely linked to human activities. In Hạ Long Bay, rapid urbanization, industrial development, port construction, and tourism-related waste have collectively contributed to elevated turbidity and increasing levels of landscape and water pollution. Without systematic strategies for dredged sediment treatment, recycling of construction materials, and stricter monitoring of industrial effluents—including those from coal-industry operations in Ha Long—reclamation-driven degradation of coastal ecosystems will be exacerbated [65].

The long-term sustainability of industrial activities in Hai Phong – Ha Long depends on the adoption of sustainable production practices. Industrial zones, particularly Dinh Vu–Cat Hai and coastal coal-based industries, should integrate cleaner production technologies, circular economy principles, and eco-industrial park models to minimize emissions and resource consumption. Experiences from Singapore and the Netherlands demonstrate that reclamation projects aligned with sustainability frameworks are more resilient, balancing industrial growth with ecosystem conservation [1,5,10].

5. Conclusion

Coastal reclamation in the Hai Phong – Ha Long region has profoundly transformed natural coastal ecosystems into artificial structures supporting industrial, urban, and tourism development. Over 7,000 hectares of sensitive ecosystems—including mangroves, tidal flats, seagrasses, and shallow coastal waters—have been converted since 1990, leading to direct biodiversity loss and ecosystem degradation. Although some restoration efforts, such as mangrove replanting, have been implemented, they remain limited in scale compared to the extent of degradation.

The impacts of reclamation extend beyond ecological loss. Changes in water quality—characterized by rising levels of organic pollutants and nutrients—have been observed, especially in the dry and transition seasons. Seabed morphology has also shifted due to altered sediment dynamics and erosion-accretion patterns. Furthermore, the depletion of natural capital and decline in fisheries highlight the socio-economic consequences of unregulated reclamation.

In light of these findings, sustainable coastal planning and stricter environmental safeguards are critical to balancing development with long-term ecological and economic health in the Hai Phong – Ha Long region. To achieve this balance, several practical recommendations are proposed: (i) delineating ecological red lines where reclamation is prohibited; (ii) mandating sediment treatment and recycling in large-scale projects; (iii) strengthening post-project environmental impact assessments with transparent reporting; and (iv) adopting integrated coastal zone management (ICZM) to coordinate industrial, tourism, and ecological functions.

Future research should focus on (i) long-term monitoring of ecosystem changes using satellite remote sensing and in-situ surveys, (ii) assessing cumulative socio-economic costs of reclamation projects, and (iii) developing spatial planning models that explicitly integrate circular economy principles and eco-industrial park frameworks. Such research will provide a stronger scientific basis for adaptive management and policy-making in the Hai Phong – Ha Long coastal region.

Author Contributions

T.D.L.: Conceptualization, methodology, validation, data curation, writing - review and editing; D.T.T.H.: Conceptualization, methodology, validation, data curation, writing - review and editing; N.V.T.: writing - review and editing; N.T.T.H.: writing - review and editing; N.D.V.: writing - review and editing; B.M.T.: writing - review and editing. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest. All authors have approved the manuscript and report no financial interests.

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