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SENTINEL-2 REMOTE SENSING APPLICATION IN TYPICAL PORT AREAS OF VIETNAM: LACH HUYEN, LIEN CHIEU AND CAN GIO

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Abstract

Seaports are vital gateways driving Vietnam's socio-economic development. However, large-scale port expansion and construction have significantly altered land use/land cover (LULC) and affected coastal environments. This study applies multi-temporal remote sensing (Sentinel-2 imagery from 2022-2025) to analyze spatial changes in three key areas: Lach Huyen Port (Hai Phong) - a mega port built on reclaimed land; Lien Chieu Port (Da Nang) - an expanded port; and Can Gio (Ho Chi Minh City) - the proposed site of an international transshipment hub. Using Google Earth Engine (GEE), shoreline positions were extracted. LULC mapping and change detection employed NDWI/MNDWI indices combined with supervised classification. Results show that: Lach Huyen developed more than 1,200 ha of port infrastructure from reclamation, Lien Chieu expanded by about 350 ha, while Can Gio maintained a stable mangrove ecosystem, serving as a baseline dataset for future monitoring. The study highlights remote sensing as an effective tool supporting sustainable planning, management, and environmental monitoring of major seaport areas.

Keywords: *Remote sensing, shoreline change, Lach Huyen, Lien Chieu, Can Gio.*

1. Introduction

In Vietnam, with a coastline of more than 3,260 km, holds a strategic position for developing its maritime economy, in which the seaport system plays a central role [1]. To meet the growing demand of trade, the Government approved the Master Plan for the Development of Vietnam's Seaport System—an important strategy to transform Vietnam into a strong and prosperous maritime nation [2]. This process has promoted the construction of new ports and the expansion of many existing ones, especially large-scale deep-water ports

However, this rapid development inevitably leads to profound changes in land use/land cover (LULC), putting great pressure on coastal environments [3]. Activities such as land reclamation, dredging, and infrastructure development can alter shorelines, affect ecosystems, and disrupt sediment processes. Therefore, continuous monitoring and quantitative assessment of these changes are essential to ensure sustainable development [4].

Traditional field surveys are often costly, time-consuming, and unable to provide consistent coverage across large areas [5]. Remote sensing technology, with its ability to provide multi-spectral, multi-resolution, and multi-temporal data, has proven to be a powerful and effective tool for addressing this issue [6]. Sentinel satellite imagery has been widely applied worldwide to monitor coastal changes and large construction sites [7].

This study selects three representative port areas at different stages of development: (1) Lach Huyen Port (Hai Phong): A mega port entirely constructed through large-scale land reclamation; (2) Lien Chieu Port (Da Nang): An existing port undergoing significant investment, upgrading, and expansion; (3) Can Gio Port (Ho Chi Minh City): A potential international transshipment port project located in a sensitive ecosystem [8].

The present research investigates and calculates waterline and port area changes using Sentinel-2 satellite imagery on the Google Earth Engine platform at these three sites. Sentinel-2 was selected due to its free access, higher spatial resolution than Landsat, and more frequent revisit cycles. In this study, we processed and extracted the waterline using remote sensing indices. After selecting the classification algorithm with higher accuracy, a series of classified maps and corresponding waterlines at different time periods were generated. Finally, the results were visualized and analyzed using MapInfo software.

The study focuses on major construction and development zones including the Lach Huyen International Port, the expansion of Lien Chieu Port, and the planned Can Gio Port in Vietnam (Figure 1). With strategic geographical, political, and economic locations, these areas play vital roles in maritime transportation. Their naturally deep waters are suitable for accommodating large vessels, making them ideal for port investment and development.

a. Lach Huyen International Port: Located in Cat Hai District, Hai Phong City, this is the first deep-water port in Northern Vietnam. Construction began in 2013, and the port has been operational with continuous expansion. The area is characterized by extensive reclamation and development on intertidal flats [9].

b. Lien Chieu Port: Situated in the northwest of Da Nang Bay, it is one of the key general ports in Central Vietnam. The expansion project (Phase 1) started in late 2022 to relieve congestion at Tien Sa Port and meet the growing cargo demand [10].

c. Can Gio Port plan: Planned in Phu Loi Islet, Thanh An Commune, Can Gio District, Ho Chi Minh

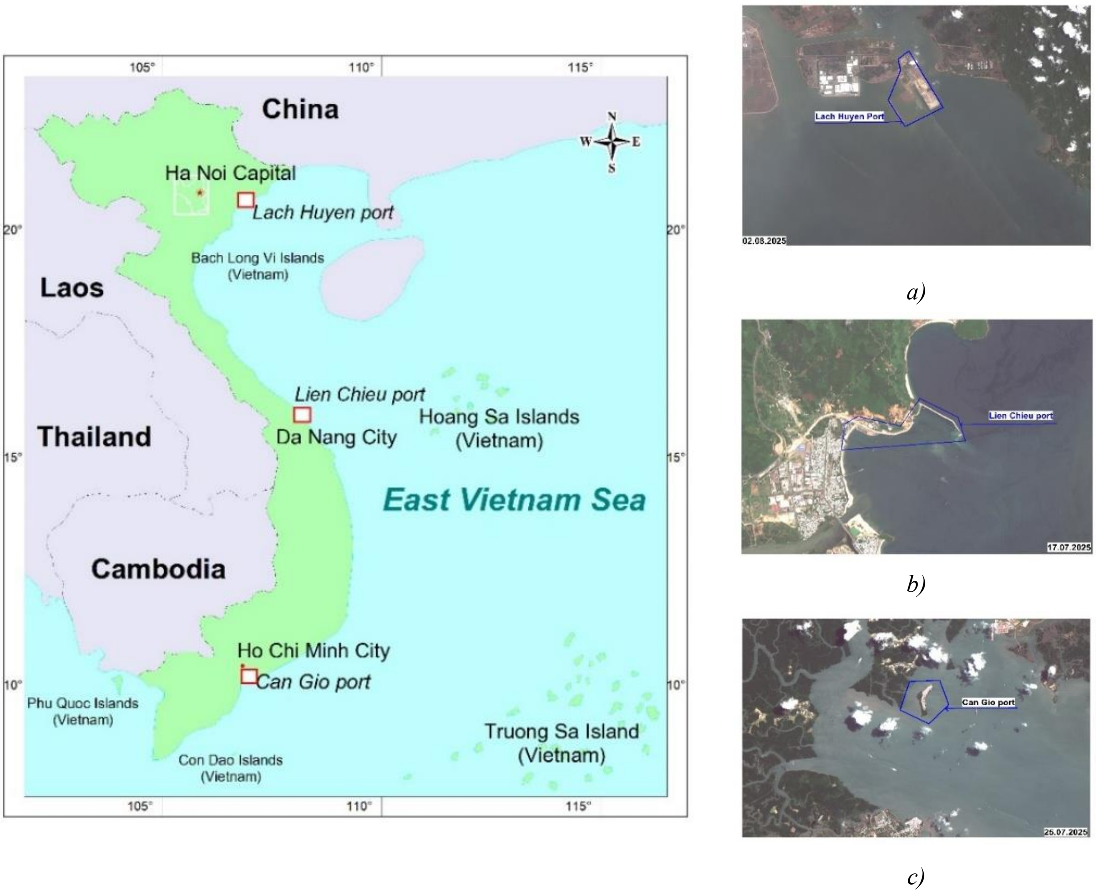

Figure 1. Study Areas

(a. Lach Huyen International Port (top-right); b. Lien Chieu Port (middle-right); c. Can Gio Port (bottom-right))

City. This large-scale project is located near the Long Tau River estuary and adjacent to the Can Gio Mangrove Biosphere Reserve, a UNESCO-recognized heritage site [11].

The dataset consists of Sentinel-2 image series (2022-2025) with 10 m resolution, processed on the Google Earth Engine (GEE) platform.

2. Materials and methods

2.1. Materials

This study uses optical satellite imagery from Sentinel-2: Images with 10 m spatial resolution collected during 2022-2025 were used to evaluate port construction scale and shoreline changes in adjacent areas [12]. Sentinel-2 provides data every 5 days, with acquisition time over Vietnam between 10:20-10:35 local time.

All images were accessed through Google Earth Engine (GEE), a cloud-based platform supported by NASA and ESA for remote sensing data processing. GEE enables fast access and efficient processing of free satellite imagery. Images with less than 10% cloud cover over the study areas were selected.

2.2. Methodology

Google Earth Engine (GEE) was employed throughout the image interpretation process, using indices to differentiate water bodies from other features. The Normalized Difference Water Index (NDWI) and Modified NDWI (MNDWI) were applied, with MNDWI being particularly important in port areas where concrete structures could be confused with water.

As shown in Figure 2, the workflow of this study consists of four main steps: Step 1 - Data Collection: Sentinel-2 multispectral images were acquired for multiple time periods covering the study areas (Lach Huyen, Lien Chieu, and Can Gio); Step 2 - Feature Selection: Spectral features relevant to water and other land surface elements were identified using water-related indices such as the Normalized Difference Water Index (NDWI) and the Modified NDWI (MNDWI); Step 3 - Image Processing and Segmentation: Image enhancement and threshold-based segmentation were applied to delineate the water-land boundary based on the selected indices; Step 4 - Result Extraction: The extracted waterlines for each time period were vectorized to prepare for subsequent shoreline change analysis.

Preprocessing of raw satellite imagery followed standard procedures [13]: (1) Radiometric Calibration: Converting digital numbers (DN) to spectral radiance values; (2) Atmospheric Correction: Using the FLAASH algorithm (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) to remove atmospheric effects and convert radiance to surface reflectance [14]; Geometric Correction: Images were reprojected to WGS 84 / UTM Zone 48N.

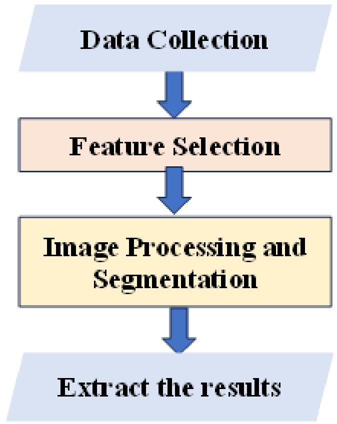

Figure 2. Shoreline extraction process

The waterline was extracted from Sentinel-2 imagery using remote sensing-based water indices, including the Normalized Difference Water Index (NDWI) and the Modified NDWI (MNDWI). These indices were applied to enhance the spectral contrast between land and water surfaces. After performing atmospheric and geometric corrections, threshold-based segmentation was conducted to delineate the water-land boundary. The classified outputs were produced using the supervised classification algorithm that achieved the highest overall accuracy. Finally, the extracted waterlines were visualized and cross-checked in MapInfo software to ensure spatial consistency and topological accuracy.

The Otsu algorithm was applied to optimize threshold selection from MNDWI-classified images. Training sites were carefully chosen as representative areas; mis-selection could significantly affect accuracy.

Interpretation was particularly challenging in Can Gio and Lach Huyen due to the presence of fishing boats, aquaculture cages, and highly dynamic tidal flats. Mangrove forests, characterized by low tidal mudflats, exhibit substantial shoreline variability depending on tidal conditions.

The Support Vector Machine (SVM) algorithm was chosen due to its proven high performance in remote sensing classification [15]:

- Five major LULC classes were identified: (i)

Water bodies; (ii) Port infrastructure/built-up land; (iii) Vegetation (agriculture, shrubs); (iv) Mangroves (applicable in Can Gio), and (v) Bare land/intertidal flats.

- Training samples (ROIs) were collected based on high-resolution Google Earth imagery and field knowledge. The SVM classifier was trained with these samples and applied to the full dataset.

2.3. Remote Sensing Indices

For each image, water-related features were computed (Table 1).

Table 1. Lists the indices used for water extraction

Index	Formula
NDVI	$NDVI = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$
NDWI	$NDWI = \frac{GREEN - \text{NIR}}{\text{NIR} + \text{RED}}$
MNDWI	$MNDWI = \frac{GREEN - MIR}{GREEN + MIR}$

Sentinel-2's Multispectral Instrument (MSI) detects 4 spectral bands, including visible light (GREEN, RED), Near-Infrared (NIR) and Mid-Infrared (MIR), with resolutions ranging from 10 meters.

Post-classification comparison: Change matrices were generated by overlaying LULC maps from different years to quantify transitions between land cover classes [16].

NDVI (Normalized Difference Vegetation Index): Applied to assess vegetation health and change [17].

NDWI: Applied to separate water bodies and monitor shoreline change [18].

MNDWI: were applied with particularly important in port areas where concrete structures could be confused with water.

3. Results and Discussion

The overall accuracy of the classified maps exceeded 90%, with Kappa coefficients greater than 0.85, indicating reliable results for change analysis.

3.1. Changes at Lach Huyen International Port

LULC analysis at Lach Huyen revealed the most dramatic changes (Figure 3).

- Before 2022, the area was dominated by water bodies and tidal flats.

- 2022 - 2025, port infrastructure expanded dramatically, covering more than 1,200 ha, mainly converted from water and intertidal flats.

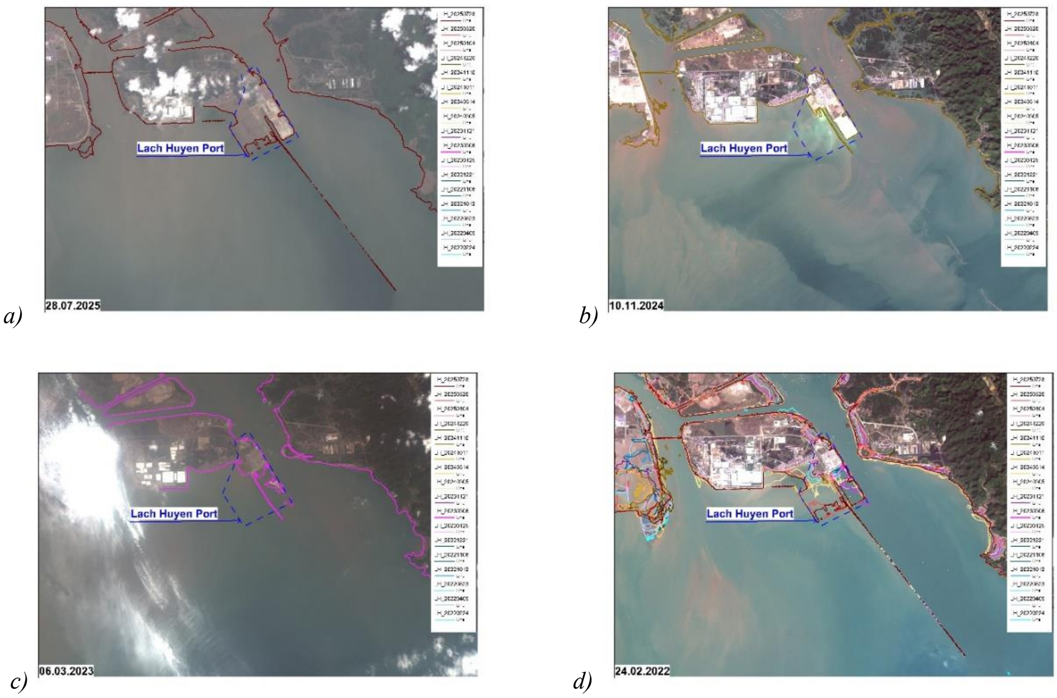

Figure 3. Shoreline changes at Lach Huyen International Port (2022-2025)

(a. July 28, 2025; b. Nov. 10, 2024; c. Mar. 6, 2023; d. Composite shoreline and Feb. 24, 2022 base image)

- MNDWI analysis clearly showed the emergence of docks, breakwaters, and the entire offshore logistics zone.

- In Figures 3a and 3d, low-tide conditions expose sand barriers, while Figures 3b and 3c at high tide reveal only breakwaters and constructed port facilities.

3.2. Changes at Lien Chieu Port

Changes in Lien Chieu were less abrupt than in Lach Huyen but still significant (Figure 4).

- Between 2022-2025, port infrastructure expanded by approximately 350 ha, mainly reclaimed from water bodies and bare land.

- MNDWI analysis illustrated distinct construction progress of project components.

3.3. Changes at Can Gio Port plan

The 2023-2025 analysis serves as a baseline dataset. Results indicate that the planned port area remains largely covered by mangroves and water bodies (Figure 5).

- No significant anthropogenic land cover change was observed.

- This baseline is crucial for future monitoring, enabling accurate assessment of environmental impacts once the project is implemented.

3.4. Dicussion

Development Models: The study identifies two distinct models of seaport development: (1) the "land reclamation model" at Lach Huyen, and (2) the "land-based expansion model" at Lien Chieu. Each model entails unique environmental impacts. The reclamation model directly alters hydrodynamic regimes and benthic ecosystems, potentially causing erosion or sedimentation in adjacent areas [19, 20]. In contrast, the land-based expansion model places pressure on terrestrial resources, possibly leading to the loss of agricultural land or changes in land-use purposes [21].

Implications for Planning and Management: Remote sensing data provide objective evidence on the pace and scale of urbanization. For Lach Huyen and Lien Chieu, managers can use these data to monitor compliance with planning policies and assess the effectiveness of environmental mitigation measures [6]. For Can Gio, the baseline dataset serves as an early warning tool. Any future changes in mangrove extent can be rapidly detected, consistent with global studies on mangrove monitoring [22, 23].

Limitations and Future Directions: This study employed medium-resolution imagery (10-30 m).

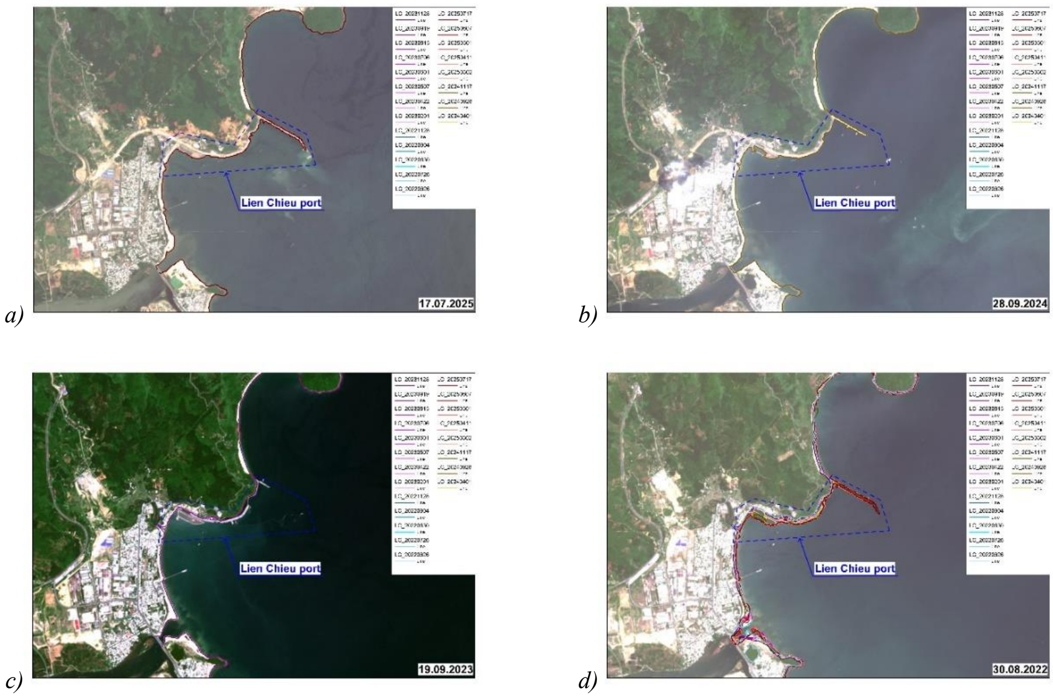

Figure 4. Shoreline changes at Lien Chieu Port (2022–2025)

(a. July 17, 2025; b. Sep. 28, 2024; c. Sep. 19, 2023; d. Composite shoreline and July 26, 2022 base image)

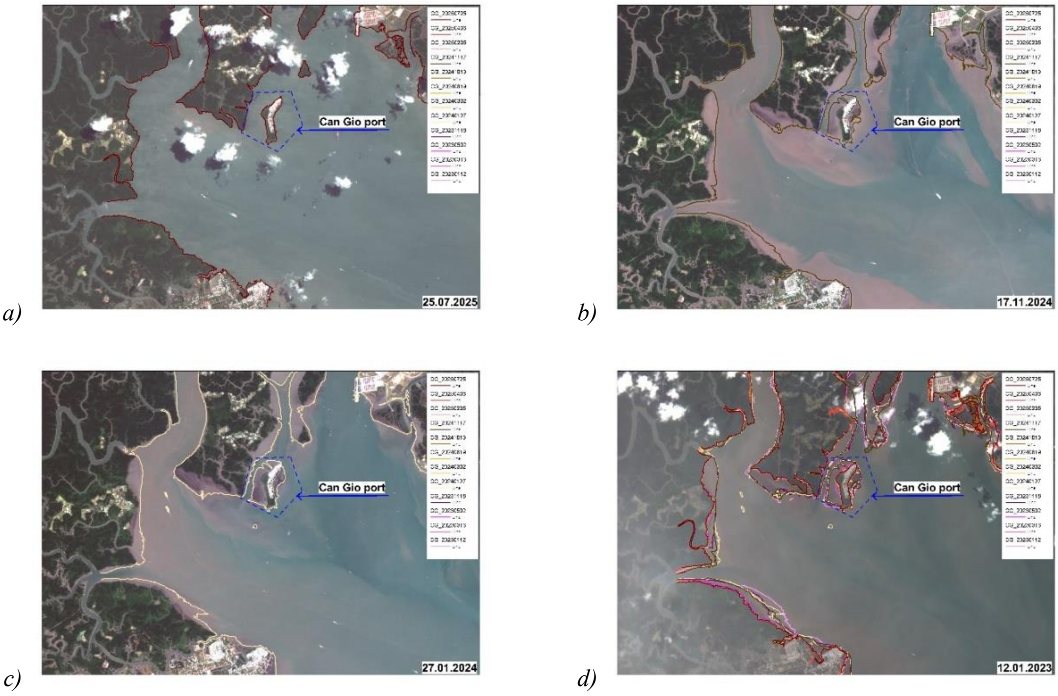

Figure 5. Shoreline changes at Can Gio Port plan (2023–2025)

(a. July 20, 2025; b. No. 17, 2024; c. Jan. 27, 2024; d. Composite shoreline and Jan 12, 2023 base image)

Integrating very high-resolution images or Drone/UAV data could provide more detailed insights into small-scale changes, such as vegetation health or specific construction activities [15]. In addition, the tidal regime also has a significant influence on shoreline determination. Therefore, incorporating hydrodynamic models to simulate sediment transport, along with socio-economic models, would provide a deeper understanding of the causal relationships between port development and environmental impacts, thereby supporting more comprehensive decision-making [24].

4. Conclusion

This study successfully demonstrated the capacity of remote sensing and GIS technologies to monitor and assess changes in complex port areas of Vietnam. The findings provide critical spatial information supporting policymakers, managers, and scientists in pursuing sustainable seaport development, balancing economic growth with environmental protection.

By applying multi-temporal remote sensing, the study quantified and analyzed land use/land cover (LULC) changes at three representative seaports, each reflecting different development models. Using Sentinel-2 imagery from 2022-2025, the research arrived at the port areas of Vietnam: Lach Huyen International port, Lien Chieu Port and Can Gio Port plan.

In summary, the findings not only provide quantitative evidence of the pace and scale of seaport development but also clarify distinct environmental impact models. The datasets generated are objective and valuable inputs for policymakers, environmental managers, and planning consultants in evaluating planning effectiveness, monitoring cumulative impacts, and building sustainable development strategies that harmonize economic interests with ecological conservation.

Future research should focus on integrating higher-resolution remote sensing data with hydrodynamic modeling to provide deeper insights into erosion, sedimentation, and water quality changes in these port areas.

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