Mapping wind turbine tower locations in Ca Mau coastal region using Sentinel-1 synthetic aperture radar images

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Abstract:

Ca Mau province is a coastal region with strong and fairly stable winds, less affected by storms. By July 2025, Ca Mau province has 13 completed and operational wind farms. The increasing number of wind energy projects shows that monitoring the development of wind energy projects is essential. The objective of this study is to detect the persistent construction structures on sea, specifically wind towers built off the shore of Ca Mau province. This study used the two-dimensional polarization space method on Sentinel-1 time-series radar images to identify the locations of wind turbine towers off the shore of Ca Mau province. The results showed that the confounding effects of complex variations in incident and azimuth angles of the Sentinel-1 synthetic aperture radar (SAR) images have been completely eliminated. In addition, the method used in this study was successful in mapping persistent construction structures with Sentinel-1 time-series SAR images. The accuracy of results was evaluated by observing and collecting ground truth data in the study area. With very high accuracy, this method can be applied to map the locations of persistent construction structures at sea at other wind farm projects in the future.

Keywords: *Synthetic Aperture Radar; wind turbine tower; Ca Mau coastal region*

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1. Introduction

Located in the coastal region of the Mekong Delta, Ca Mau province has a 310 km long coastline, is a coastal area with strong and quite stable winds (average wind speed is 7 m/s), less affected by storms, floods, earthquakes, tsunamis [1]. Implementing the resolutions of the National Assembly, the Government on socio-economic development and ensuring national defense and security as well as taking advantage of the potential that nature has given, Ca Mau province has issued many policies and strategies to attract many investment resources to develop renewable energy sources, creating a breakthrough for rapid and sustainable socio-economic development.

By July 2025, Ca Mau province has 13 completed and operational wind farms. Ca Mau province (old) has 5 wind energy projects put into commercial operation with a total capacity of 170 MW including: Tan Thuan Wind Energy Plant Project Phase 1 with a capacity of 25 MW and Phase 2 with a capacity of 50 MW; Tan An 1 Wind Energy Plant Project Phase 1 with a capacity of 25 MW; Vien An Wind Energy Plant Project with a capacity of 25 MW; Tan An 1 Wind Energy Plant Project Phase 2021-2025 with a capacity of 45 MW. the Tan An 1 Wind Energy Plant Project Phase 2021-2025 with a capacity of 30 MW is currently under construction. Bac Lieu Province (old) has 8 wind farms being completed and put into operation, 2 wind farms under construction on land and offshore.

In Ca Mau province, the application of remote sensing data mainly focuses on a number of areas such as determining the current status of coastal land use; distribution and reserves of coastal mangrove forests; assessing the situation of coastal erosion and sedimentation; assessing changes in the current status of rice land use and monitoring rice crops. The application of remote sensing data in monitoring offshore construction structures in wind energy projects in coastal areas of Ca Mau province is still new and has not been studied. Meanwhile, more and more wind energy projects are being planned, constructed and developed in coastal areas of Ca Mau province.

Information on the locations and construction period of wind energy projects built in coastal areas is an extremely important geospatial data source to monitor the changes of coastal ecological environment as well as long-term land use planning. Collecting the data using traditional methods by conducting field surveys over large areas are time consuming and costly. Meanwhile, Sentinel-1 synthetic aperture radar (SAR) data can provide information on the location of wind energy projects with a 12-day cycle repeating once over a large area covering the entire Ca Mau province. Therefore, the study aims to monitor the development of wind energy projects in recent times in order to provide information for land use planning in Ca Mau coastal region.

2. Methods

2.1 Image processing

Time-series Sentinel-1 SAR images were pre-processed to derive the backscatter coefficient in decibel (dB) for each pixel. The pre-processed steps included applying orbit file, thermal noise removal, radiometric calibration and terrain correction using the Shuttle Radar Topography Mission (SRTM) 30-m topographic data [2]. Then spatial co-registration of temporal data based on a referenced image was conducted to obtain the time series data in the same coordinate system. All these steps were carried out in the GEE platform.

To reduce speckle noise in SAR images, we utilised a multi-temporal 3-point mean filter (a moving average over a given time window) that would be computationally effective for noise elimination [3]. The calculation was implemented as follows:

$$p_{mean(ij\ at\ t)} = average(p_{ij\ at\ t-1}:p_{ij\ at\ t+1}) \qquad (1)$$

In Equation (1), $p_{mean(ij\ at\ t)}$ is the output pixel value at location i,j (i: numbers of image rows, j: numbers of image columns) at time t; $p_{ij\ at\ t-1}$ is the input pixel value at location i,j at time t-1; and $p_{ij\ at\ t+1}$ is the input pixel value at location i,j at time t+1.

In this case study, t has a value in the range of 1 to 35 (35 being the total number of SAR images in the period under consideration). After the mean calculation, the first and the last images in the time series were removed and only 33 images were used for further analysis.

2.2 Mapping

We used 2-dimensional (2-D) space of VV-VH polarizations to determine the threshold for building structures. A pixel was assigned to a building class on land if it satisfied the following conditions: VH backscatter greater than −12 dB (VH > −12 dB) or VV backscatter greater than −5 dB (VV > −5 dB). We can also detect building structures on the sea surface [2], where VH backscatter greater than −20 dB (VH > −20 dB) or VV backscatter greater than −5 dB (VV > −5 dB). If a pixel did not satisfy that condition, it would be assigned to a non-building class.

To account for missing building pixels, the VV and VH thresholds were applied to all Sentinel-1A images in the time series (33 images). All output images (with value 1 for building pixels, and with value 0 for non-building pixels) were combined to count the number of times that each pixel was identified as building. If pixel_ij was detected as a building T times out of the 33 images, then the count of pixel_ij was set to T. Each pixel in the combined output image could have a value of T from a minimum of 0 (for pixels in which buildings were never identified) to 33 (for pixels identified as buildings at all the times). To minimize misclassifying building pixels from real non-building pixels, the optimal building count threshold (building_count_threshold) with the discrete derivative of building pixels (Δm_n) was determined depending on where the Δm_n curve became invariant or flattened. Pixel_ij was identified as a building if building_count_ij > building_count_threshold where the building_count_threshold could be from 1 to 33. The discrete derivative of building pixels was calculated as follows:

$$\Delta_{m\_n} = N_{threshold\_m} - N_{threshold\_n} \quad (2)$$

where the terms: Δ_{m_n} for the derivative between thresholds m and n, $N_{threshold\_m}$ for the number of building pixels at threshold m ($1 \le m \le 33$), and $N_{threshold\_n}$ for number of building pixels at threshold n ($1 \le n \le 33$). We found that count threshold = 9 (i.e., building count = 10 or more) is optimal as the derivative curves are flattened for larger values of the count threshold [3]. The mapping result of building structure can be used as a mask for other land cover classes.

3. Results and discussion

The map of Bac Lieu wind energy plant in the period of March 2017 – April 2018 (Figure 1) and the period of November 2022 – January 2024 (Figure 2) shows that coastal land use in the area has changed by the presence of new persistent construction structures.

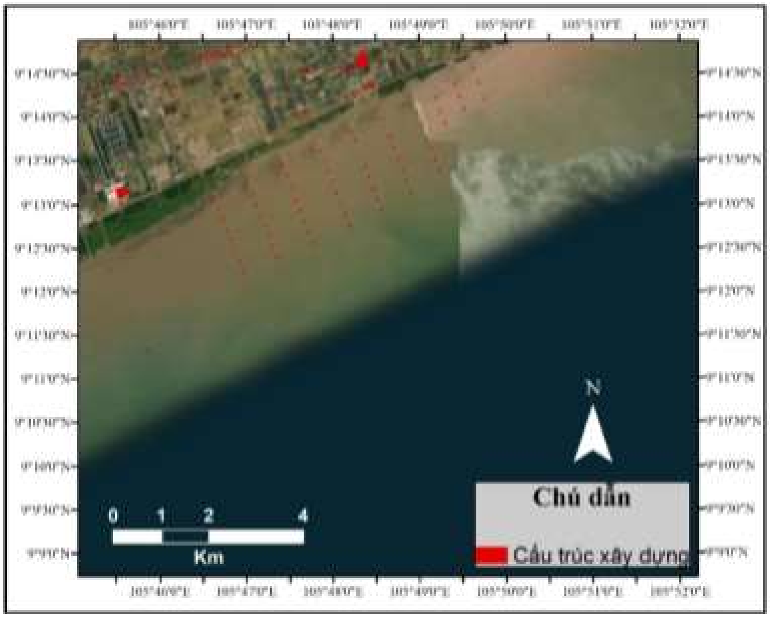

Figure 1. *Location map of Bac Lieu wind energy plant in the period of March 2017 – April 2018.*

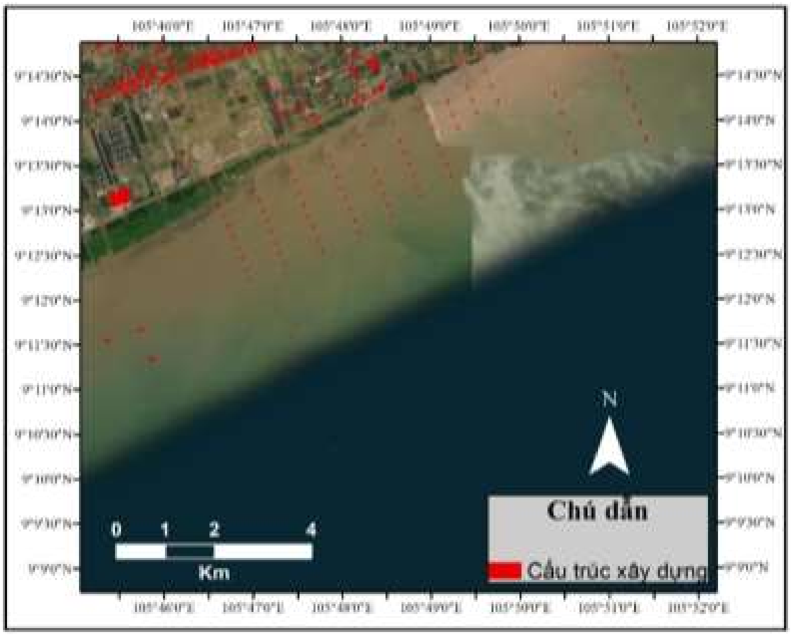

Figure 2. *Location map of Bac Lieu wind energy plant in the period of November 2022 – January 2024.*

The map of the Hoà Bình 1 wind energy plant (Figure 3) shows that in the period of August 2020 – October 2021 there are a few persistent construction structures were built in the coastal regions.

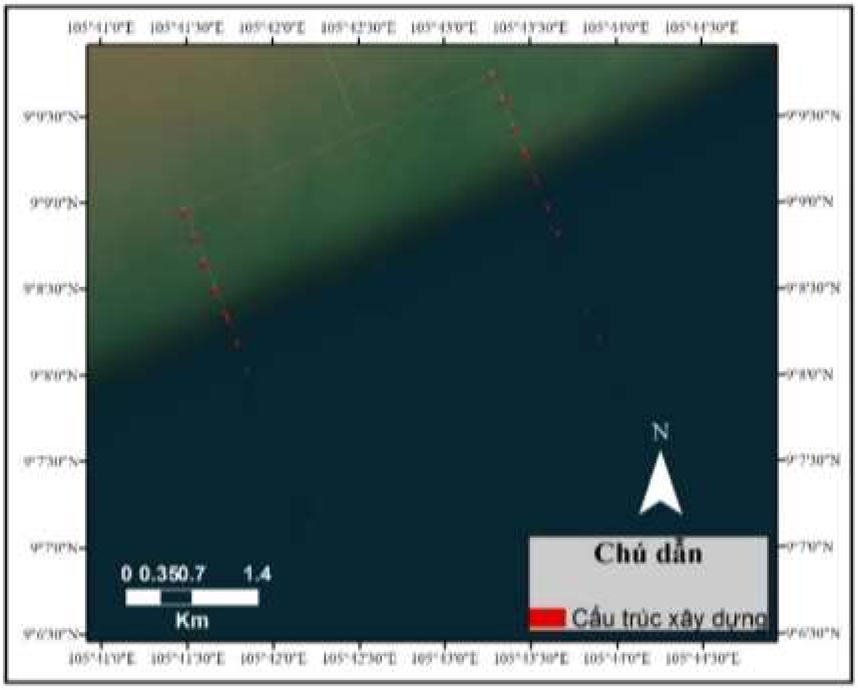

Figure 3. *Location map of Hoa Binh 1 wind energy plant in the period of August 2020 – October 2021.*

The map of the Hoà Bình 1 wind energy plant (Figure 4) shows that there are two rows of persistent construction structures arranged parallel to each other, each row has 13 construction structures and the distance between two adjacent construction structures is equal.

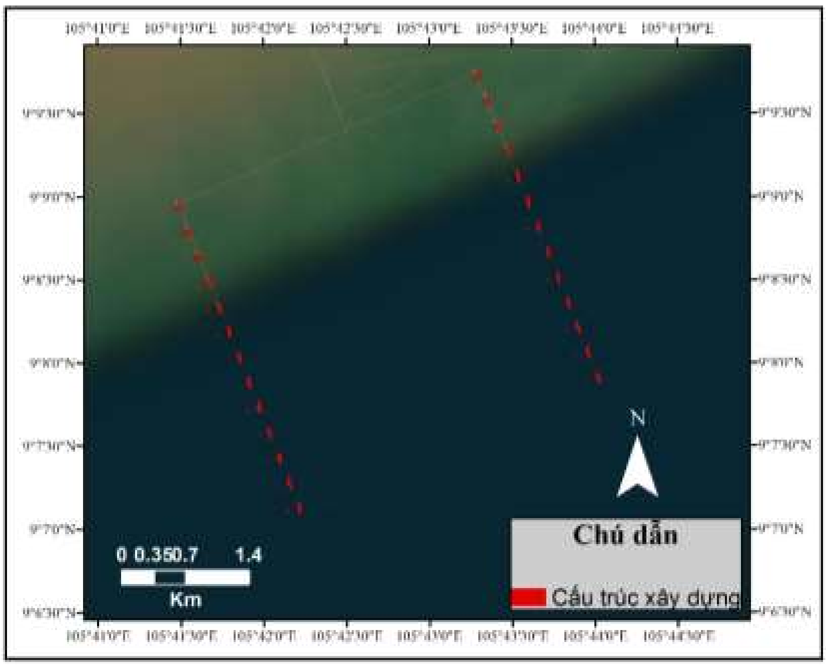

Figure 4. *Location map of Hoa Binh 1 wind energy plant in the period of November 2022 – January 2024.*

Figure 5 presents the map of persistent construction structure (wind turbine tower) of Tân Thuận 1 (Ca Mau) wind energy plant. There are three unparallel rows of persistent construction structures.

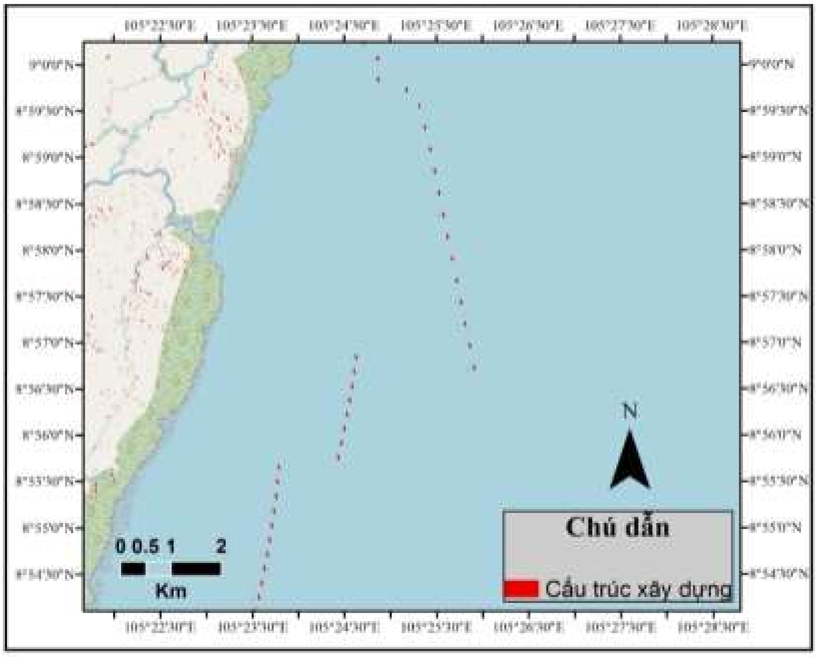

Figure 5. *Location map of Tan Thuan 1 (Ca Mau) wind energy plant in the period of January 2024 – June 2025.*

Figure 6 presents the map of persistent construction structure (wind turbine tower) of Viên An (Ca Mau) wind energy plant. There is only one row of persistent construction structures.

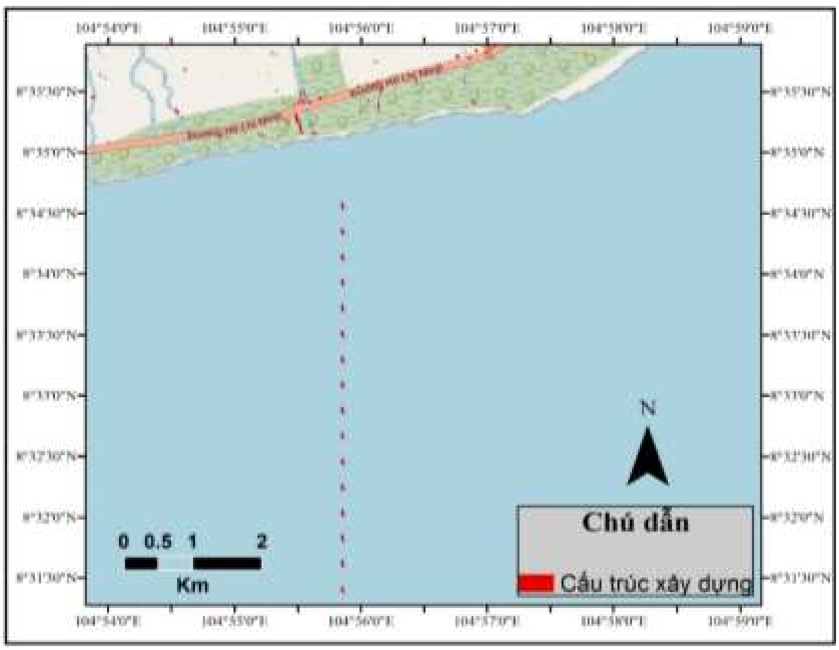

Figure 6. *Location map of Vien An (Ca Mau) wind energy plant in the period of January 2024 – June 2025.*

4. Conclusion

This study has presented an innovative method to map persistent construction structures on coastal region using times-series records of satellite Sentinel-1 SAR data. The results were validated with in-situ and field truth observations obtained in Ca Mau coastal regions. The conclusion from this study includes the following key points:

The novel use of satellite Sentinel-1 SAR data in the two-dimensional polarization domain enables the method to be robust against confounding factors such as variations due to different incidence and azimuth angles.

A demonstration of the ability of radar backscatter signatures to map persistent construction structures (wind turbine towers) is founded on radar responses to true physical structures of construction rather than optical colors or spectral appearances of land cover types [4] [5]. As our method is based on radar signatures of physical construction structures, it can successfully capture the characteristics of construction patterns corresponding to different rural-urban landscapes in both inland and coastal regions.

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Conflicts of Interest

The authors declare no conflict of interest.

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