

DETERMINING SEASONAL SEAFLOOR DEPTH CHANGES AROUND OFFSHORE ISLANDS OF VIETNAM USING SENTINEL-2 AND GOOGLE EARTH ENGINE

Nhu Hung Nguyen^{1,*}, Van Phu Le¹, Van Son Nguyen²

¹*Institute of Techniques for Special Engineering, Le Quy Don Technical University*

²*Faculty of Radio-Electronic Engineering, Le Quy Don Technical University*

Abstract

This study focuses on determining bathymetric changes around offshore islands of Vietnam using remote sensing data available on the Google Earth Engine cloud platform. Sentinel-2 multispectral satellite imagery was collected over three time periods, January 14, 2020, June 5, 2020 and June 15, 2021, coinciding with the wind season to analyze and calculate bathymetric changes. The results of the bathymetry compared to the field measurement points have coefficients of determination (R^2) ranging from 0.83 to 0.94. The Relative Mean Square Error (RMSE) results obtained were 0.066 m, 0.048 m and 0.079 m, initially providing a map of seasonal bathymetry changes consistent with reality. This method demonstrates the efficiency and automation potential for tracking depth changes in the Vietnamese coastal region, especially around offshore islands. Moreover, it highlights the importance of continuous monitoring for environmental protection, navigation, and resource management.

Keywords: *Bathymetry; remote sensing; Sentinel-2; Google Earth Engine; offshore islands; climate change.*

1. Introduction

Monitoring bathymetric changes is a crucial component of oceanographic research, marine resource management, and environmental protection. The seabed hosts a variety of important natural resources, including hydrocarbons, minerals, and marine biodiversity, making it vital to monitor and understand its dynamic behavior over time. Bathymetric changes can occur due to natural processes such as erosion, sediment deposition, and tectonic activity, as well as human-induced factors like dredging and offshore infrastructure development.

Traditional methods for bathymetric measurement include single-beam and multi-beam sonar systems and airborne LiDAR. These methods, while accurate, are often

* Corresponding author, email: nguyennhuhung@lqdtu.edu.vn
DOI: 10.56651/lqdtu.jst.v7.n02.897.sce

limited by their high cost, time-consuming nature, and restricted spatial coverage [1]. They also require specialized equipment and personnel, making it difficult to achieve continuous, large-scale bathymetric monitoring, especially in offshore or hard-to-reach areas [2].

With the advancement of satellite remote sensing, it has become possible to estimate bathymetry from space. Satellite-based methods offer a cost-effective and efficient way to monitor large areas regularly, with the added benefit of accessing historical data to study changes over time. Sentinel-2, with its high-resolution multispectral imagery, has proven to be a valuable resource for bathymetric studies [3, 4]. The availability of this data on the Google Earth Engine (GEE) platform further enhances its usability, providing a powerful cloud-based tool for accessing, processing, and analyzing large datasets in real-time [5].

This study focuses on identifying seasonal changes in bathymetry around offshore islands of Vietnam using remotely sensed data available on the GEE platform. By leveraging remote sensing and cloud computing, this study seeks to demonstrate a more efficient approach to bathymetry monitoring that can be applied to other coastal areas in the future.

2. Materials and methodology

2.1. Study area

The study was conducted on the Truong Sa Islands, focusing on offshore islands characterized by complex marine dynamics. The specific area chosen for this study spans approximately 9 km in length and 1.8 km in width, oriented along a northeast-southwest axis. The area has a lake bed and is surrounded by coral reefs, sandbanks and seagrass beds, which are highly sensitive to environmental changes. These islands are not only ecologically significant but also strategically important for national security. The study area is subject to dynamic environmental processes such as wave action, tidal changes and sediment transport, making it a suitable location to study bathymetric variations. In addition, the surrounding waters support a diversity of marine life and any bathymetric changes could have far-reaching ecological impacts.

2.2. Data sources

For this study, Sentinel-2 satellite data was used, which is available on the GEE platform. Sentinel-2 provides optical imagery with a spatial resolution of 10 meters for visible and near-infrared bands, making it ideal for shallow water studies. The data collected includes surface reflectance values from the Blue (Band 2), Green (Band 3), and

Red (Band 4) bands, which are particularly useful for analyzing water properties and estimating depth in coastal and offshore regions.

Data was collected for three specific time periods: January 14, 2020, June 5, 2020 and June 15, 2021. These timeframes were chosen based on cloud cover, as minimal cloud cover ensures the most accurate surface reflectance readings. The images were preprocessed within GEE, including atmospheric correction using the Sen2Cor algorithm, cloud masking, and the exclusion of land and other non-water objects. The preprocessing steps are critical to ensure that only high-quality data is used for bathymetric estimation.

In addition to satellite data, tidal measurements and in-situ depth data from field surveys were used to validate the bathymetric estimates and adjust for tidal fluctuations. These measurements help to improve the accuracy of the bathymetric models by providing ground truth data.

2.3. Methodology

The methodology used in this study involves the following key steps:

Preprocessing Sentinel-2 imagery:

The Sentinel-2 images were filtered based on cloud cover and atmospheric conditions using GEE's cloud masking capabilities. Non-water areas were removed using threshold values specific to the study area: Green band reflectance ($\rho_{GREEN} > 0.01$), Red band reflectance ($\rho_{RED} < 0.1$), and Near-Infrared band reflectance ($\rho_{NIR} < 0.03$). This process ensures that the data used for depth estimation corresponds only to water bodies, thereby minimizing the impact of noise from land or cloud cover.

Bathymetric estimation:

The next step is to apply the Normalized Difference Water Index (NDWI) to enhance the contrast between water and land features to extract the water surface. The NDWI index was calculated according to the following formula [6]:

$$NDWI = \frac{\rho_{GREEN} - \rho_{NIR}}{\rho_{GREEN} + \rho_{NIR}} \quad (1)$$

where ρ_{GREEN} , ρ_{NIR} are reflectance values in the GREEN (Band 3) and NIR (Band 8) bands of the Sentinel-2 multispectral image. The reflectance values were then used to calculate the remote sensing reflectance (R_{rs}) using established algorithms. The Stumpf algorithm, which correlates water depth with the attenuation of blue and green light, was used for estimating water depth [7]. This algorithm is widely used for deriving bathymetry from

multispectral satellite imagery due to its ability to account for varying water clarity and bottom types [8].

Additionally, the concentration of chlorophyll-a (Chl-a) was incorporated into the model to refine the depth estimates [9, 10]. Chlorophyll-a concentrations affect the optical properties of water and can influence the accuracy of depth retrieval. In this study, a fixed Chl-a value of 0.5 mg/m³ was used based on previous research in similar regions [5]. The depth estimation parameters (m and n) of the Stumpf algorithm are respectively calculated according to formulas (2) and (3):

$$m = a \cdot e^{(0.957 \cdot \text{Chl-a})} \quad (2)$$

$$n = b \cdot e^{(0.957 \cdot \text{Chl-a})} \quad (3)$$

Finally, the study estimates water depth by quantifying the different attenuation levels between the blue and green image bands [7]:

$$\text{Depth} = m \frac{\ln(1000 \cdot r_{rs \text{ blue}})}{\ln(1000 \cdot r_{rs \text{ green}})} + n \quad (4)$$

To determine the values of a and b , the authors used field measurement data combined with a linear regression algorithm. The parameters m and n will be calculated after the linear regression process.

Tidal and calibration adjustments:

After estimating the depth, tidal data from three time periods were used to adjust the bathymetric values to a consistent tidal reference. The tidal difference between January 14, 2020 (0.4 m) and June 5, 2020 (1.6 m) was 1.4 m, and between June 5, 2020 and June 15, 2021 (1.8 m) was 0.4 m. This correction for variation ensures that the bathymetric changes reflect actual seafloor movements rather than tidal fluctuations. In situ bathymetric measurements collected during field surveys were also used to calibrate the bathymetric estimates, improving the accuracy and reliability of the results.

Change detection:

Finally, the image difference has been used to detect depth changes between the times. By deducting depth values with the same pixel position, the discovery map has been created to visualize the areas where the depth variants occur.

3. Results and discussion

Figure 1, 2, 3 respectively present Sentinel-2 satellite images of the study area on January 14, 2020, June 5, 2020, and June 15, 2021. The images are displayed in a natural color composite (Red - Green - Blue).

Figure 4 depicts the field measurement points. The number of points is 253, with depths ranging from 0 m to 1.1 m. Next, Fig. 5, 6, 7 show the depth determined from the collected Sentinel-2 satellite images. Overall, the depth varies from 0 m to below 15 m. Additionally, the depth increases towards the center of the basin in the study area.

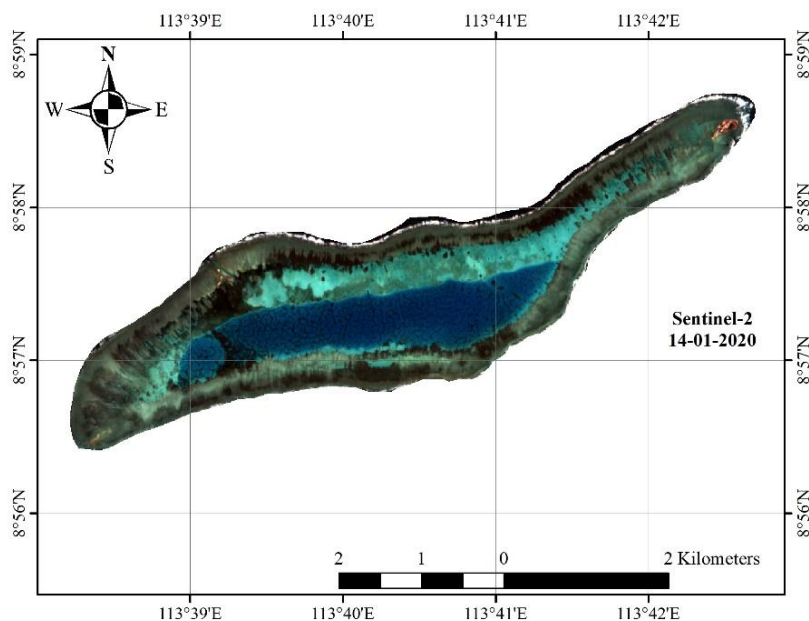


Fig. 1. Sentinel-2 images of the research area collected on January 14, 2020.

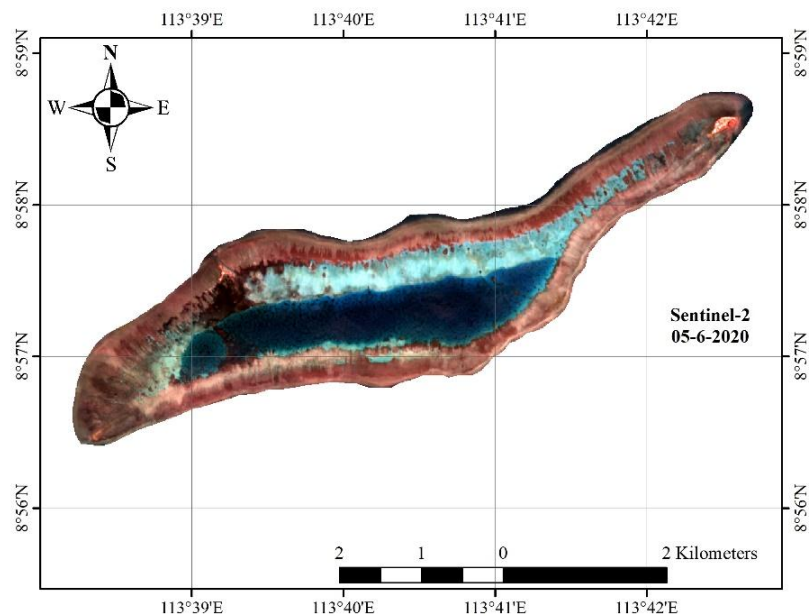


Fig. 2. Sentinel-2 images of the research area collected on June 5, 2020.

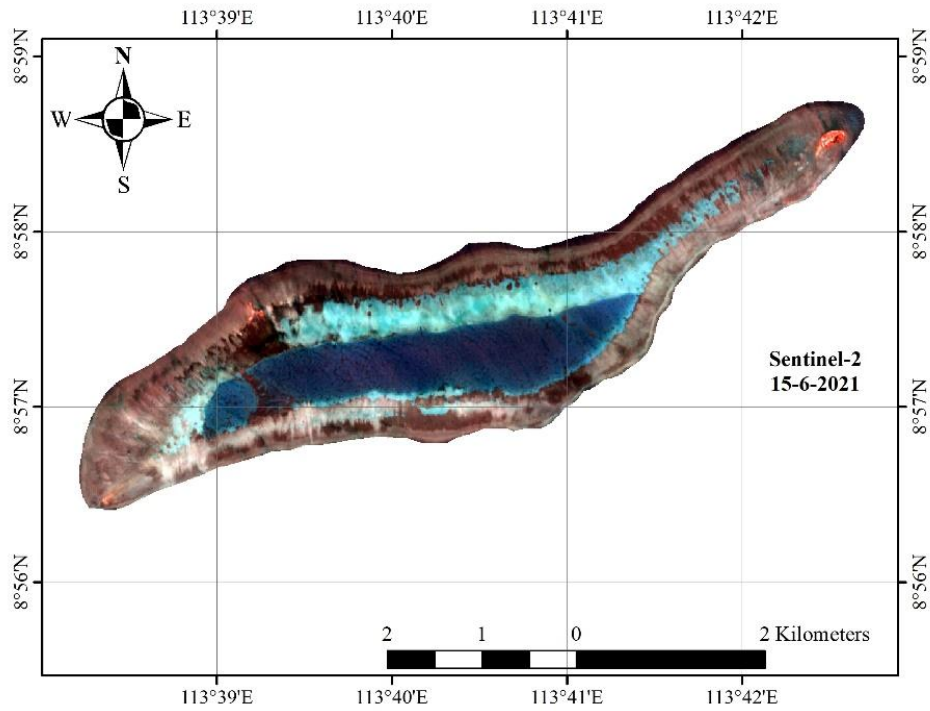


Fig. 3. Sentinel-2 images of the research area collected on June 15, 2021.

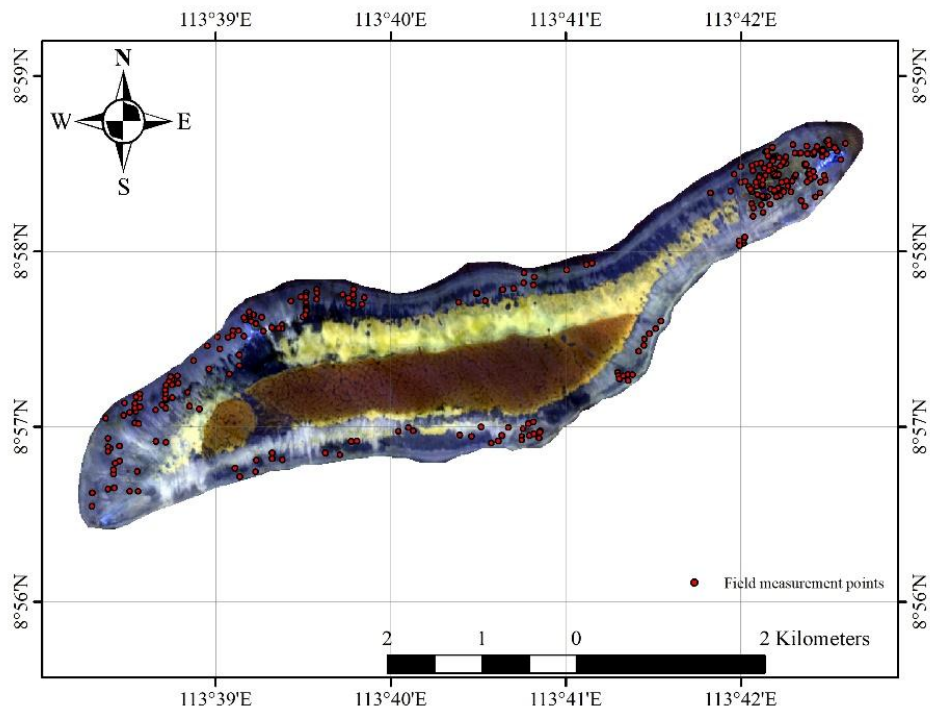


Fig. 4. Distribution of field measurement points.

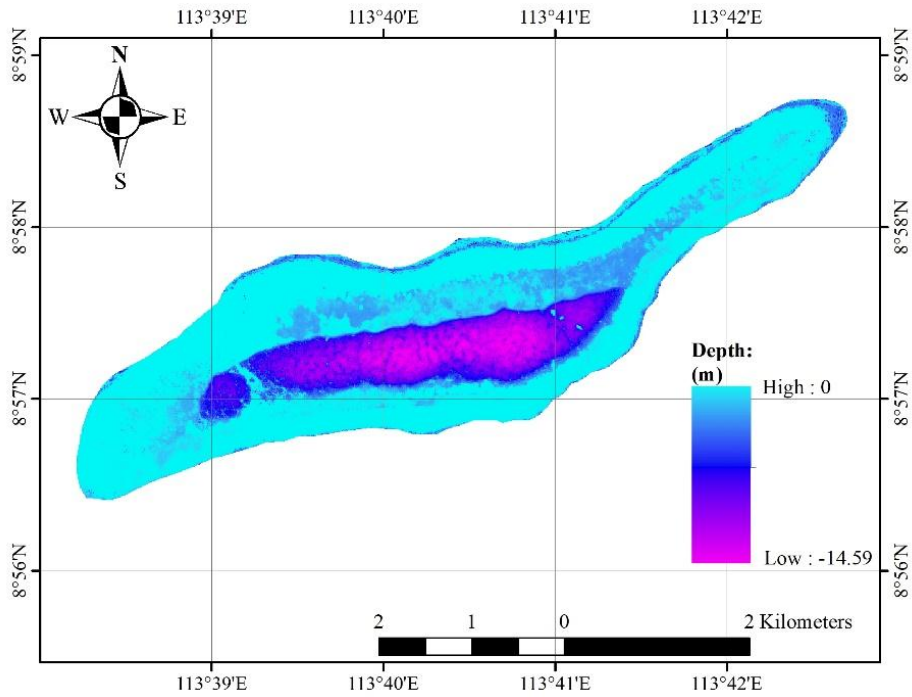


Fig. 5. Bathymetric map determined from Sentinel-2 satellite image on January 14, 2020.

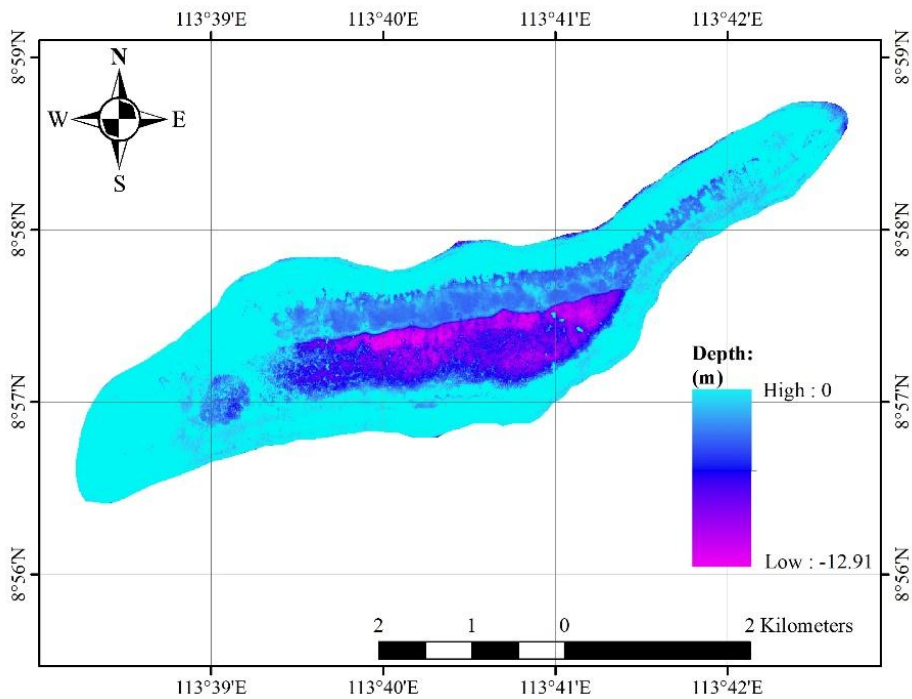


Fig. 6. Bathymetric map determined from Sentinel-2 satellite image on June 5, 2020.

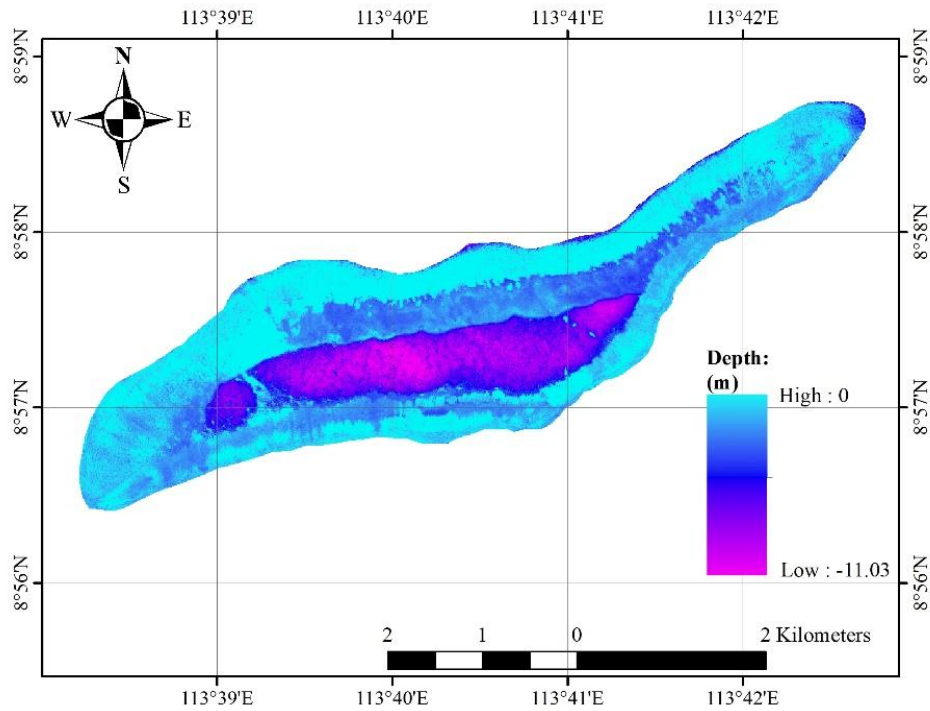


Fig. 7. Bathymetric map determined from Sentinel-2 satellite image on June 15, 2021.

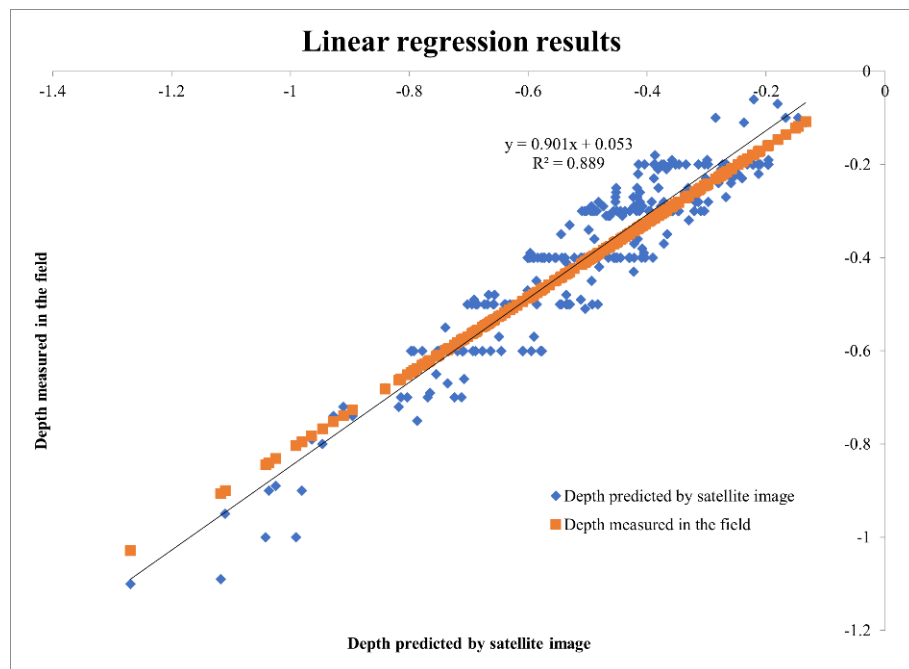


Fig. 8. Compare the results of depth determination from Sentinel-2 satellite image on January 14, 2020 with actual results.

Figure 8, 9, 10 show linear regression results between the satellite-derived bathymetry and the actual measured bathymetry. The coefficient of determination (R^2) values ranged from 0.834 to 0.948, indicating that the model explained 83.4% to 94.8% of the variance in the observed data, indicating a high level of accuracy. These high R^2 values indicate that the regression model is well suited to predicting shoreline bathymetry, with minimal unexplained variance. However, small variations in R^2 values between models may reflect differences in data quality, environmental factors such as water clarity, seabed type or wave and current interference at different times.

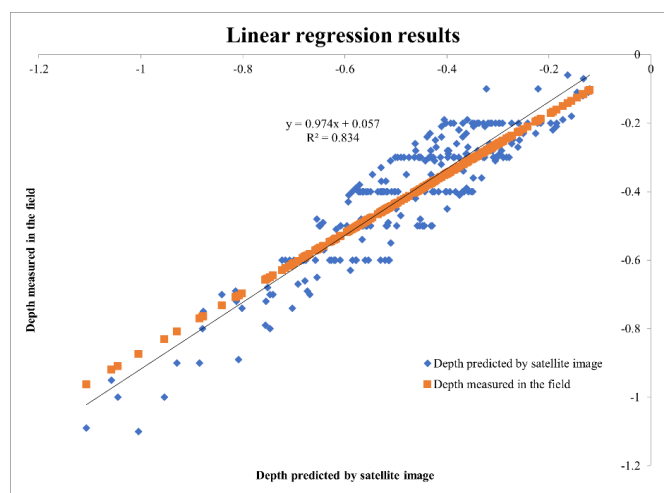


Fig. 9. Compare the results of depth determination from Sentinel-2 satellite image on June 5, 2020 with actual results.

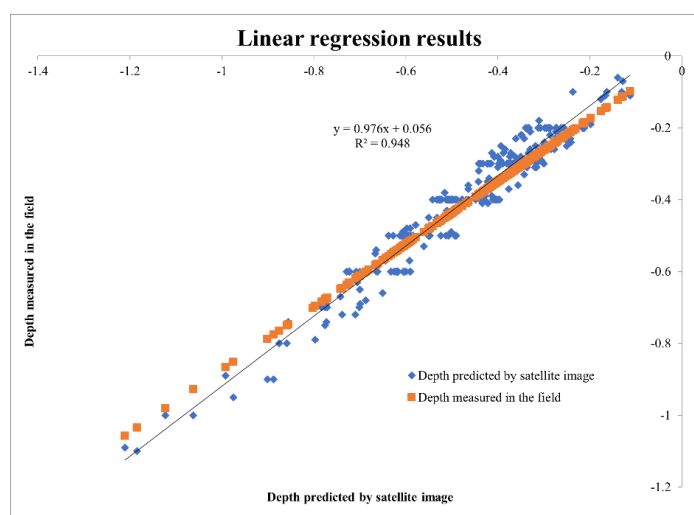


Fig. 10. Compares the results of depth determination from Sentinel-2 satellite image on June 15, 2021 with actual results.

The RMSE results of 0.066 m, 0.048 m and 0.079 m represent the average deviation between the predicted and actual depths, with these small values indicating that the model performs well in terms of prediction accuracy. Among these, the lowest RMSE value of 0.048 m indicates that the model is particularly reliable in specific areas, likely due to more consistent satellite data or less influence by environmental noise. The differences in RMSE between time points highlight the importance of considering environmental factors that may affect the accuracy of the regression model. Overall, the combination of high R^2 values and low RMSE confirms that the model is effective in estimating shoreline depth with high confidence.

Figure 11 illustrates changes in water depth in the study area between January 14, 2020, and June 5, 2021. The map uses a color gradient to indicate depth changes, ranging from -9.92 m to 9.05 m. Areas with deeper water are shown in blue and purple, primarily concentrated in the central basin, suggesting erosion or subsidence. In contrast, shallow areas, represented in yellow and brown, indicate sediment deposition. The map reveals significant spatial variation, with non-uniform depth changes across the region.

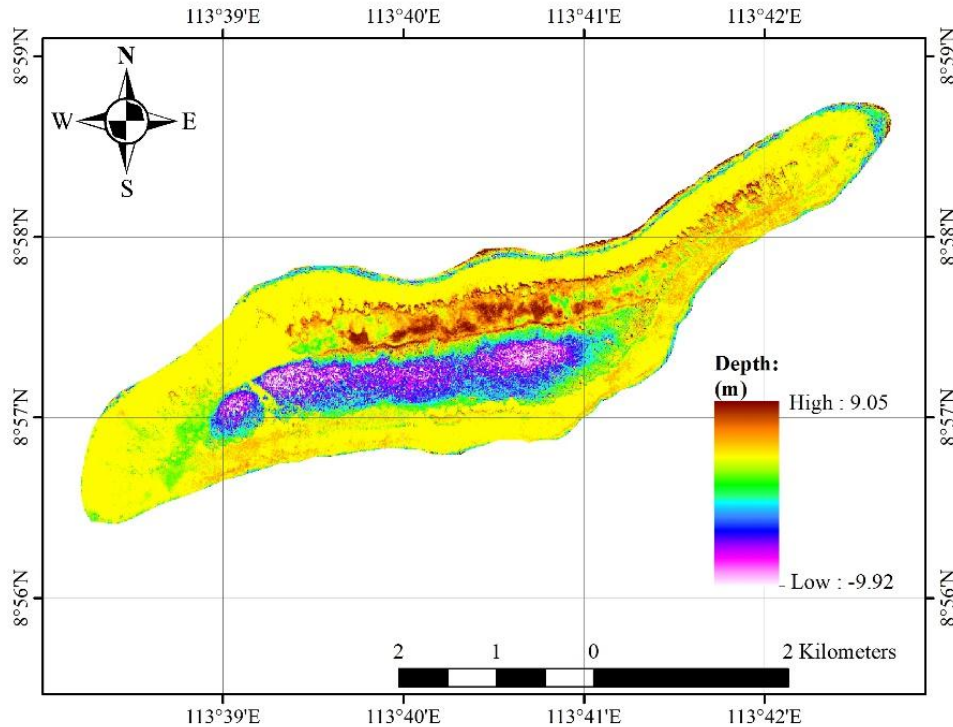


Fig. 11. Map of depth variations from January 14, 2020 to June 5, 2020.

Figure 12 captures the changes in depth within the study area between June 5, 2020 and June 15, 2021. Depths range from -7.05 m to 8.34 m, with deeper sections indicated by blue and purple hues, while yellow to brown tones show shallower regions. The central basin of the map exhibits the most substantial depth increases, likely due to erosion, whereas sediment deposition is evident in the brownish areas, resulting in shallower water.

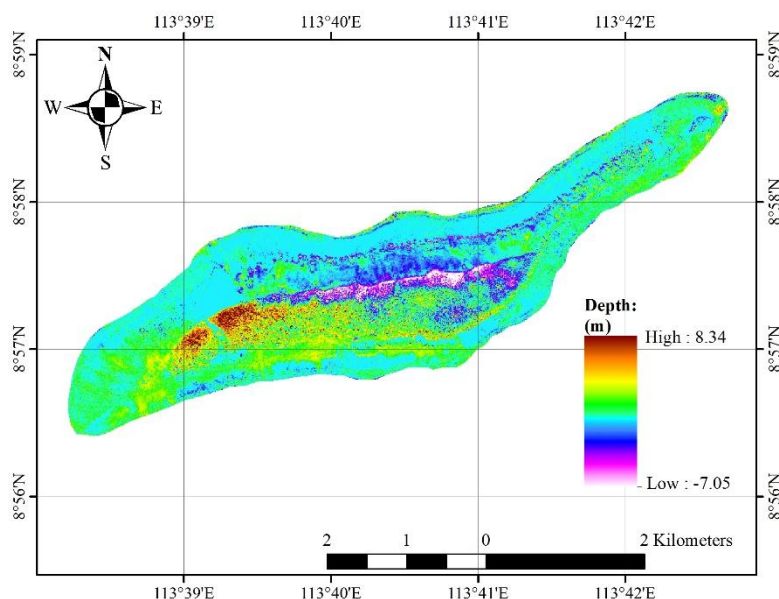


Fig. 12. Map of depth variations from June 5, 2020 to June 15, 2021.

Figure 13, 14 show the locations of the cross-sections and the corresponding depth variation values for each cross-section. Figure 14 illustrates that the central region of the study area experiences the most significant depth variation. This area, characterized by its considerable depth, is more susceptible to changes influenced by both geological dynamics and environmental factors. Geological shifts, such as tectonic movements or sediment displacement, can significantly alter the topography, while the growth and expansion of vegetation in aquatic environments may further contribute to these changes over time. Consequently, this central zone is more prone to fluctuations, making it an area of interest for monitoring both natural and environmental developments.

This variation suggests dynamic interactions between natural processes, including tidal forces, currents, and wave activity, which have reshaped the underwater topography. The clear contrasts between deep and shallow zones highlight ongoing sediment transport and geomorphological changes in the region. These findings underscore the importance of continuous observation to better understand and manage coastal erosion and sedimentation, ensuring sustainable development in the affected offshore areas.

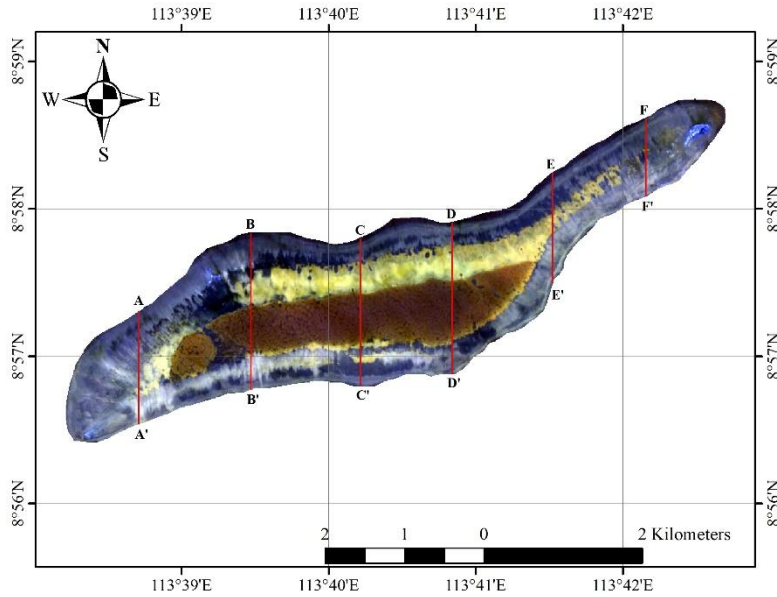


Fig. 13. Locations of the cross-sections in the study area.

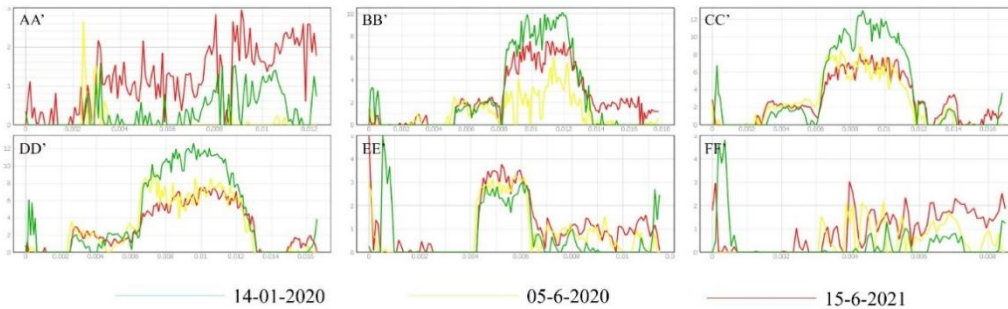


Fig. 14. The depth variation values of the cross-sections.

One of the challenges encountered during the study was the presence of cloud cover, which limited the number of usable images. However, the cloud-based processing capabilities of GEE allowed for efficient handling of large datasets, enabling the generation of reliable bathymetric maps despite these limitations.

4. Conclusion

This research demonstrates the potential of using remote sensing data, specifically Sentinel-2 imagery, in combination with the GEE platform, to monitor bathymetric changes in offshore islands. The results highlight significant depth variations in the study area, driven by natural processes such as sediment transport and coral reef dynamics. By automating the bathymetric estimation process and leveraging the power of cloud computing, this approach offers a scalable and efficient solution for continuous bathymetric monitoring.

The ability to track bathymetric changes over time has important implications for various sectors, including marine resource management, coastal planning, and environmental protection. The methodologies developed in this study can be applied to other coastal and offshore regions, contributing to more informed decision-making and sustainable management of marine environments.

Future work may involve incorporating additional satellite data, such as higher-resolution imagery or radar data, to improve the accuracy and coverage of bathymetric estimates. Furthermore, the integration of machine learning techniques could enhance the predictive capabilities of the bathymetric models, allowing for more accurate forecasting of depth changes in response to environmental factors.

Acknowledgements

This research is funded by Le Quy Don Technical University Research Fund under the grant number 24.1.60.

We would also like to thank the project “Investigate, survey, and create a detailed database of natural conditions to support the planning, design, and construction of defence, security, and socio-economic projects in the Truong Sa Islands through 2025, with a long-term vision of 2050; monitor and evaluate the impact of the natural and social environment on the archipelago for sustainable development goals” for helping to collect the data.

References

- [1] J. Zhao, B. Barnes, N. Melo *et al.*, “Assessment of satellite-derived diffuse attenuation coefficients and euphotic depths in south Florida coastal waters”, *Remote Sensing of Environment*, Vol. 131, pp. 38-50, 2013. DOI: 10.1016/j.rse.2012.12.009
- [2] D. Traganos, D. Poursanidis, B. Aggarwal, N. Chrysoulakis, and P. Reinartz, “Estimating satellite-derived bathymetry (SDB) with the Google Earth Engine and Sentinel-2”, *Remote Sensing*, Vol. 10, Iss. 6, 2018, 859. DOI: 10.3390/rs10060859
- [3] F. A. Gafoor, M. R. Al-Shehhi, C. S. Cho, and H. Ghedira, “Gradient boosting and linear regression for estimating coastal bathymetry based on sentinel-2 images”, *Remote Sensing*, Vol. 14, Iss. 19, 2022, 5037. DOI: 10.3390/rs14195037
- [4] G. Balsamo, E. Dutra, V. M. Stepanenko *et al.*, “Deriving effective lake depth from satellite lake surface temperature data: A feasibility study with MODIS data”, Technical Memorandum, No. 609, *ECMWF*, Reading, UK, 2010. DOI: 10.21957/be525ccu
- [5] J. Li, D. E. Knapp, M. Lyons *et al.*, “Automated global shallow water bathymetry mapping using Google Earth Engine”, *Remote Sensing*, Vol. 13, Iss. 8, 2021, 1469. DOI: 10.3390/rs13081469
- [6] S. K. McFeeters, “The use of the normalized difference water index (NDWI) in the delineation of open water features”, *International Journal of Remote Sensing*, Vol. 17, Iss. 7, pp. 1425-1432, 1996. DOI: 10.1080/01431169608948714

- [7] R. P. Stumpf, K. Holderied, and M. Sinclair, "Determination of water depth with high-resolution satellite imagery over variable bottom types", *Limnology Oceanography*, Vol. 48, Iss. 1, pp. 547-556, 2003. DOI: 10.4319/lo.2003.48.1_part_2.0547
- [8] N. H. Nguyen and L. V. Phu, "Bathymetric mapping of Co To island area, Quang Ninh province using sentinel-2 and landsat 8 images", *Journal of Science and Technique - Section on Special Construction Engineering*, Vol. 6, No. 01, pp. 19-28, 2023. DOI: 10.56651/lqdtu.jst.v6.n01.663.sce
- [9] J. Li, D. E. Knapp, S. R. Schill *et al.*, "Adaptive bathymetry estimation for shallow coastal waters using Planet Dove satellites", *Remote Sensing of Environment*, Vol. 232, 2019, 111302. DOI: 10.1016/j.rse.2019.111302
- [10] J. Li, Q. Yu, Y. Q. Tian *et al.*, "Spatio-temporal variations of CDOM in shallow inland waters from Landsat-8", *Remote Sensing of Environment*, Vol. 218, pp. 189-200, 2018. DOI: 10.1016/j.rse.2018.09.014

NGHIÊN CỨU XÁC ĐỊNH SỰ THAY ĐỔI ĐỘ SÂU ĐÁY BIỂN THEO MÙA XUNG QUANH CÁC ĐẢO NGOÀI KHƠI VIỆT NAM BẰNG SENTINEL-2 VÀ GOOGLE EARTH ENGINE

Nguyễn Như Hùng¹, Lê Văn Phú¹, Nguyễn Văn Sơn²

¹*Viện Kỹ thuật công trình đặc biệt, Trường Đại học Kỹ thuật Lê Quý Đôn*

²*Khoa Vô tuyến điện tử, Trường Đại học Kỹ thuật Lê Quý Đôn*

Tóm tắt: Nghiên cứu này tập trung vào việc xác định những thay đổi về độ sâu xung quanh các đảo ngoài khơi của Việt Nam bằng cách sử dụng dữ liệu viễn thám có sẵn trên nền tảng đám mây Google Earth Engine. Ảnh vệ tinh đa phổ Sentinel-2 được thu thập trong ba khoảng thời gian, ngày 14 tháng 1 năm 2020, ngày 5 tháng 6 năm 2020 và ngày 15 tháng 6 năm 2021, trùng với mùa gió để phân tích và tính toán những thay đổi về độ sâu. Kết quả đo độ sâu so với các điểm đo thực địa có hệ số xác định (R^2) dao động từ 0,83 đến 0,94. Kết quả sai số (*Relative Mean Square Error*) thu được là 0,066 m, 0,048 m và 0,079 m, ban đầu cung cấp bản đồ về những thay đổi độ sâu theo mùa phù hợp với thực tế. Phương pháp này chứng minh hiệu quả và tiềm năng tự động hóa để theo dõi những thay đổi về độ sâu ở vùng ven biển Việt Nam, đặc biệt là xung quanh các đảo ngoài khơi. Hơn nữa, nó làm nổi bật tầm quan trọng của việc giám sát liên tục để bảo vệ môi trường, điều hướng và quản lý tài nguyên.

Từ khóa: *Đo độ sâu; ảnh vệ tinh; Sentinel-2; Google Earth Engine; đảo ngoài khơi; biến đổi khí hậu.*

Received: 09/10/2024; Revised: 23/12/2024; Accepted for publication: 27/12/2024

