# BATHYMETRIC MAPPING OF CO TO ISLAND AREA, QUANG NINH PROVINCE USING SENTINEL-2 AND LANDSAT 8 IMAGES

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**Abstract**

This study developed an automated depth mapping methodology based on the surface reflection datasets of Landsat 8 and Sentinel-2 satellite imagery in Google Earth Engine. The study was conducted in the area of Co To island, Co To district, Quang Ninh province. The results of the study obtained a bathymetric map of the waters around the island, tested with 199 actual field measurement points for a coefficient of determination ($R^2$) of 0.95 with Sentinel-2 images and 0.91 with Landsat 8 images. Besides, the root mean square error (RMSE) obtained with the result of the Sentinel-2 image and Landsat 8 image is 0.145 m and 0.195 m, respectively. The initial method shows automatic, fast, efficient, and reliable results in establishing depth maps in the ocean of Vietnam, especially in coastal and archipelago areas. In addition, the method also supports regular monitoring and updates.

***Keywords:*** *Bathymetric maps; Landsat 8; Sentinel-2; Co To; Google Earth Engine.*

## 1. Introduction

The bathymetric map is a particular kind of map that displays data regarding the depth of the seabed. Numerous scientific and societal applications including topographic assessment for military operations, marine construction, and rescue operations are dependent on depth. Methods for determining water depths have changed dramatically as science has progressed. Conventional depth measurement systems have a restricted spatial range, such as single-ray, multi-ray on waterway vehicles, or LiDAR [1]. When executed, these strategies are time-consuming, costly, and labor-intensive. As a result, using free data sources that fit space and time constraints is critical [2].

Due to the disadvantages of traditional measurement methods, the method of determining depth using satellite data has been developed and shows its potential. Previous studies have applied low-resolution satellite sensors to build water object models. In the study [3, 4], the authors used MODIS (Moderate Resolution Imaging Spectroradiometer) satellite data to determine the depth of the lake area globally. The

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results of the study are applied to build lake models in weather forecasting, determining evaporation rates and accurate surface temperature forecasts. In addition, the study [5] used the SeaWiFS data source (1998 - 2003) for the purpose of locating and tracking aquatic plants and anomalies in the Mediterranean basin.

Low spatial resolution sensors can be noisy by pixels that separate water and non-water along the coast. As a result, several ground observation satellite images with high spatial and small temporal resolutions have been applied to in-depth modeling. To determine water quality, substrate composition, and depth mapping accurately, the studies used multispectral data sources such as CASI-2, and Ocean PHILLS [6-8]. In addition, the study [2] used Sentinel-2 remote sensing imagery, data collected in the Aegean Sea and Eastern Mediterranean with high resolution for depth mapping, and economic and ecological analysis of coastal edges. In addition, in the study [9], Landsat 8 satellite imagery was used to determine the reflectivity of the seafloor, while also studying underwater ecosystems.

In Vietnam, the application of remote sensing techniques to establish bathymetry has been used and shows its potential. The article [10] systematically presents the scientific basis of the method of creating bathymetric maps from Landsat 8 satellite images. In addition, in the study [11], the authors used VNREDSAT-1 data to map the bathymetry in a coastal region of Vietnam.

In recent times, many cloud computing platforms have been developed to support users to process satellite data sources and other remote sensing data. Google Earth Engine (GEE) is a powerful cloud computing platform that provides easy access to satellite datasets and fast calculation times that support depth estimates. GEE has been used in many products on a global scale including land cover, forest change, water surface area, and urban land use [2, 9].

## 2. Materials and methodology

### *2.1. Materials*

The research selected Co To island as the study area. The study conducted a test to estimate the depth of the coastal area around Co To island. Co To is in coordinates from 20°10’ to 21°15’ north latitude and from 107°35’ to 108°20’ east longitude, 60 nautical miles from land. With an area of 46.2 $km^2$, Co To is an archipelago with a rich ecosystem and a particularly important national defense and security location. Located in the Gulf of Tonkin area with more than 50 large and small islands, Co To has a section between high islands, surrounding low mountains and small sandy beaches, and small bays stretching along the island.

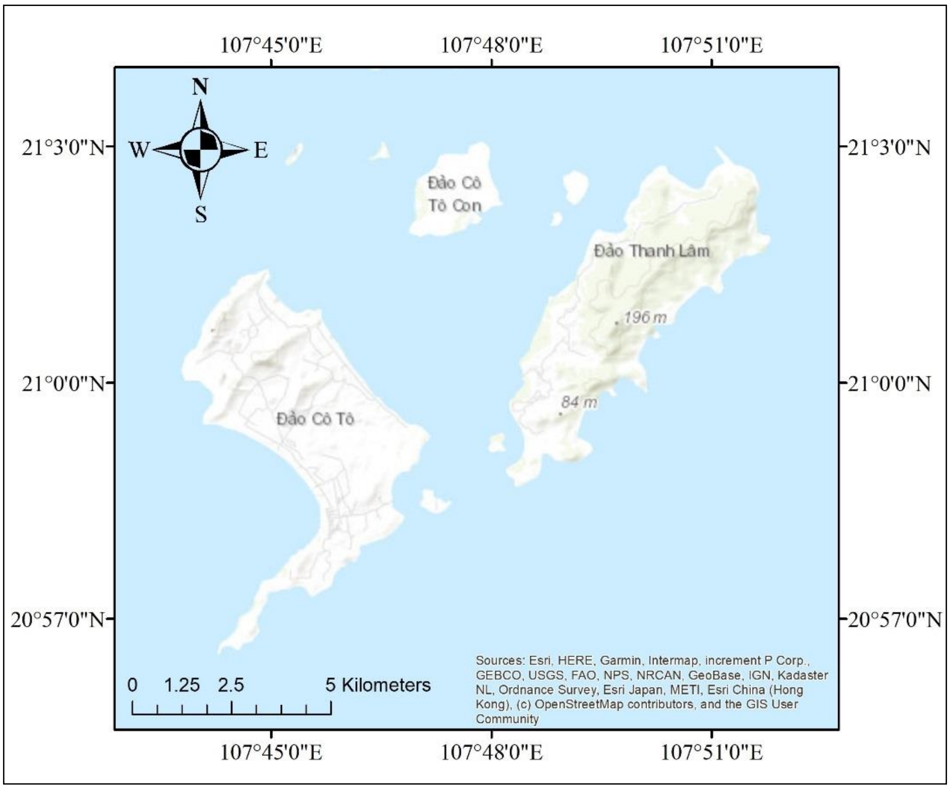


*Figure 1. Geographical location of the study area.*

The study proposes an automated depth mapping method based on the Landsat 8 and Sentinel-2 surface reflection datasets available in the Google Earth Engine cloud computing platform. Satellite imagery data is clipped around the study area for the purpose of determining the coastal and offshore depths of the islands.

### *2.2. Methodology*

The method of processing remote sensing data in the study is detailed in Figure 2. First, the study filtered the surface reflection image dataset from Landsat 8 and Sentinel-2 image data based on parameters such as study area, cloud cover, and time duration. The study selected images with minimal cloud cover over the study area. This reduces noise caused by clouds and cloud shadows during the acquisition of surface information by the sensor.

Next, the study proceeded to filter non-water objects on the reflected image, using the threshold values of the image band to filter areas of water with high turbidity, waves and reflections of sunlight. Values are used to filter objects that are suitable for each study area. For the Co To island area, the values used are $\rho_{GREEN} > 0.01$, $\rho_{RED} < 0.1$, and $\rho_{NIR} < 0.03$.

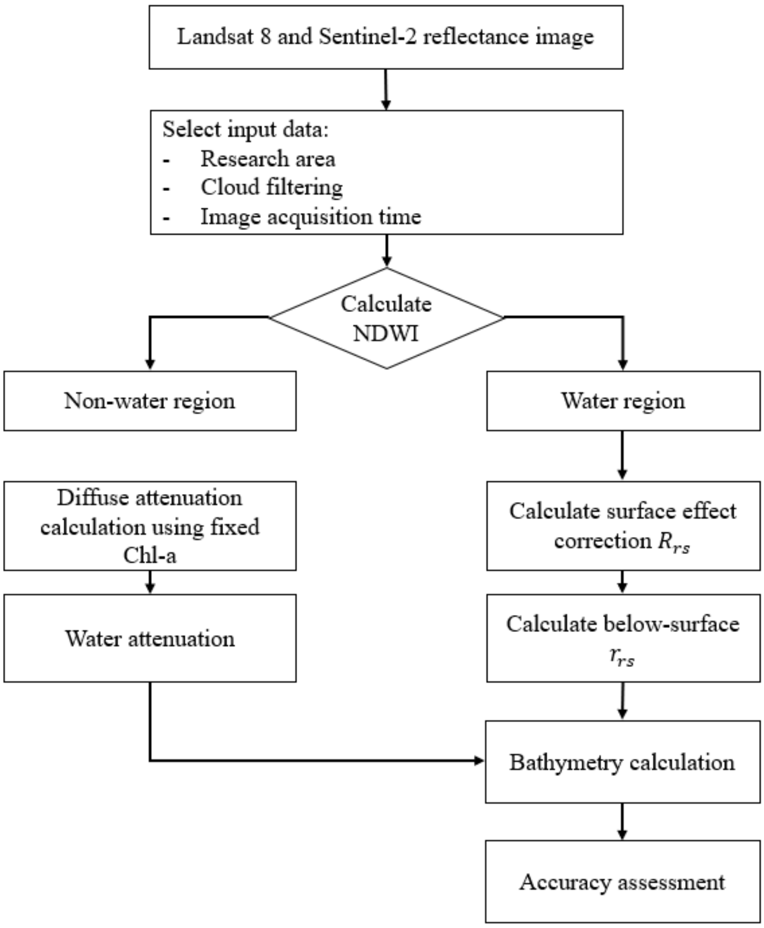


*Figure 2. Satellite data processing.*

In addition, the study further filtered non-water subjects using the Normalized Difference Water Index (NDWI) presented in formula (1):

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

Images after filtering out waterless objects are extracted for automatic depth mapping based on depth measurement algorithms [12]. Data processing is carried out on the GEE platform. First, the study calculated the remote sensing reflection value $R_{rs}$ from surface reflection data $\rho_{(\lambda)}$ [13]. The formula for calculating the remote sensing reflection value $R_{rs}$ is presented as formula (2):

$$R_{rs}(\lambda) = \frac{\rho_{\lambda}}{\pi} \quad (2)$$

Next, the study eliminated the influence between the two surfaces of air and water through the below-surface remote sensing reflection coefficient presented in formula (3) [14]:

$$r_{rs}(\lambda) = \frac{R_{rs}(\lambda)}{0.52 + 1.7 * R_{rs}(\lambda)} \tag{3}$$

After obtaining the below-surface remote sensing reflection coefficient value, the study calculated the Chlorophyll-a (*Chl-a*) concentration value for the purpose of initializing the depth estimation parameter [12]. The study used a fixed *Chl-a* value (*Chl-a* = 0.5 $mg.m^{-3}$) [15]. Based on the research [15], the depth estimate parameters ($m_0$ and $m_1$) are calculated by the formulas (4) and (5), respectively:

$$m_0 = 52.073 * e^{(0.957 * Chl-a)} \tag{4}$$

$$m_1 = 50.156 * e^{(0.957 * Chl-a)} \tag{5}$$

Finally, the study estimated water depth by quantifying the varying degrees of attenuation between the blue and green image bands [16]:

$$\text{Depth} = m_0 \frac{\ln(1000 * r_{rs} blue)}{\ln(1000 * r_{rs} green)} - m_1 \tag{6}$$

The study validates the accuracy of depths calculated through remote sensing data by comparing them with field measurement results and applying the coefficient of determination ($R^2$) and the root mean square error (RMSE) to evaluate the results.

## 3. Results and discussion

The study collected surface reflection data of the Sentinel-2 satellite in the Co To island area corresponding to the time of field measurement. The satellite data used in the study is shown in Figure 3, and the study area depth calculation is shown in Figure 4.

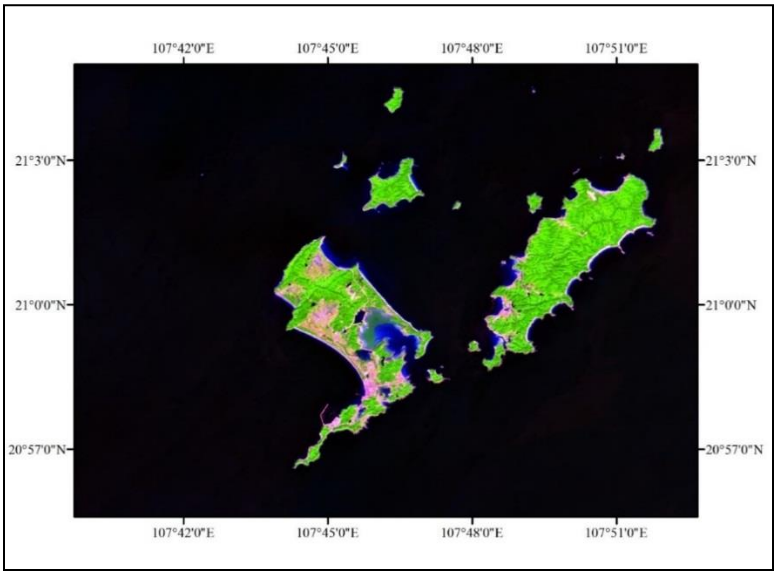


*Figure 3. Sentinel 2 (A or B) image in the Co To island, acquired on October 12, 2022.*

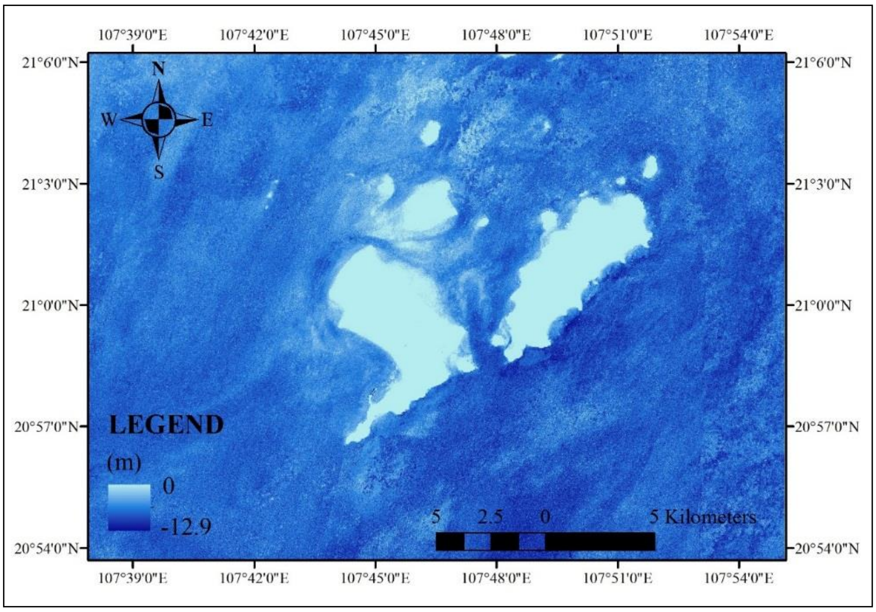


*Figure 4. Results of depth calculation of the study area using Sentinel 2 image.*

Experimented with Landsat 8 satellite imagery data, using the corresponding research method as with Sentinel-2 data. The original data and results are presented in Figures 5, 6.

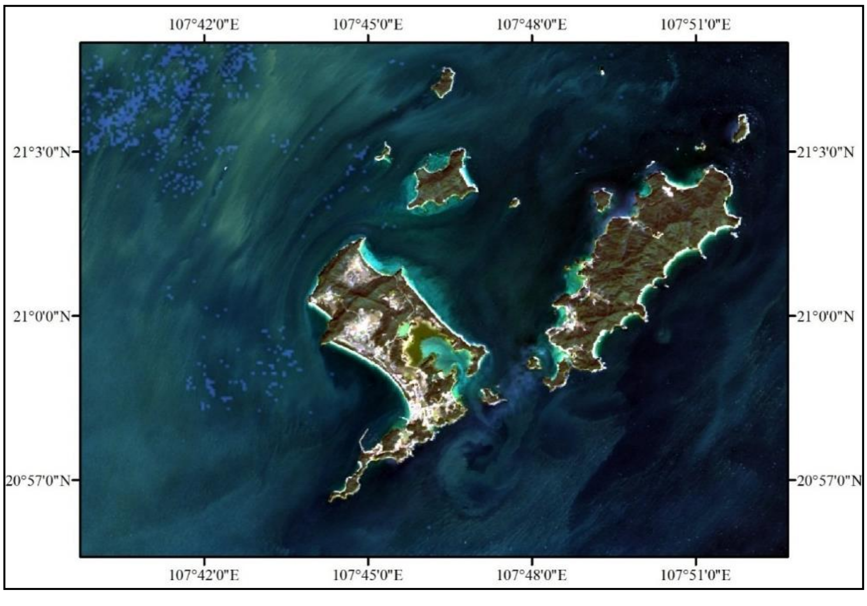


*Figure 5. Landsat 8 image in the study area, acquired on December 13, 2022.*

The study used 199 field measurement points with depths from 0 m to 6.1 m to assess the depth of the results from satellite imagery data. The actual measuring points are determined by the GNSS RTK satellite positioning method combined with single-beam echo sounding to determine the depth, with an accuracy of ± 0.3 m. The study interpolated the results of depth calculations from satellite images at the locations along with the actual measurement location, using a coefficient of determination ($R^2$) to evaluate the results of the study. The results of the study obtained depth maps of the waters around the islands, tested with actual field measurements for high coefficient of determination ($R^2$) values of 0.95 with Sentinel-2 images and 0.91 with Landsat 8 images. The initial method shows automatic, fast efficiency, and reliable results in serving the establishment of depth maps in the Vietnamese ocean. This shows that Sentinel-2 satellite data has more accurate predictions than Landsat 8 data for the Co To island area. The comparative results in the regression model are shown in Figures 8 and 9.

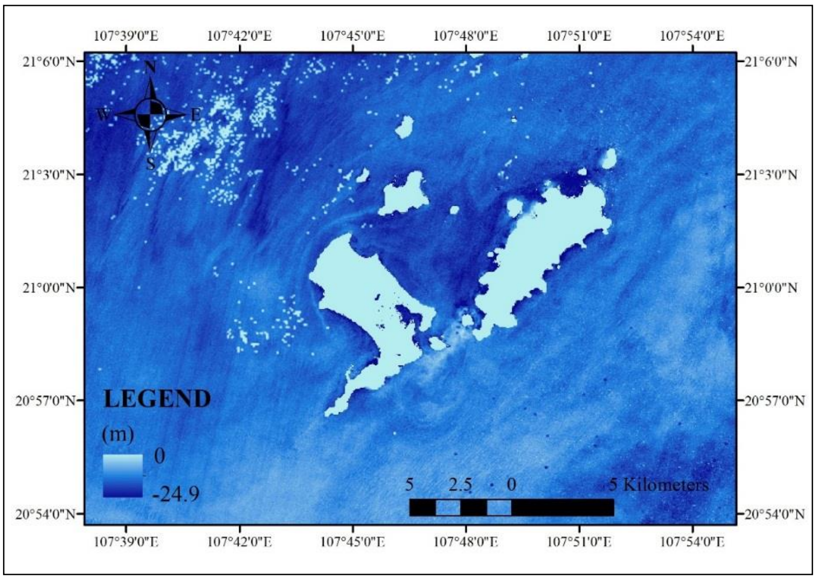


*Figure 6. Results of depth calculation of the study area using Landsat 8 image.*

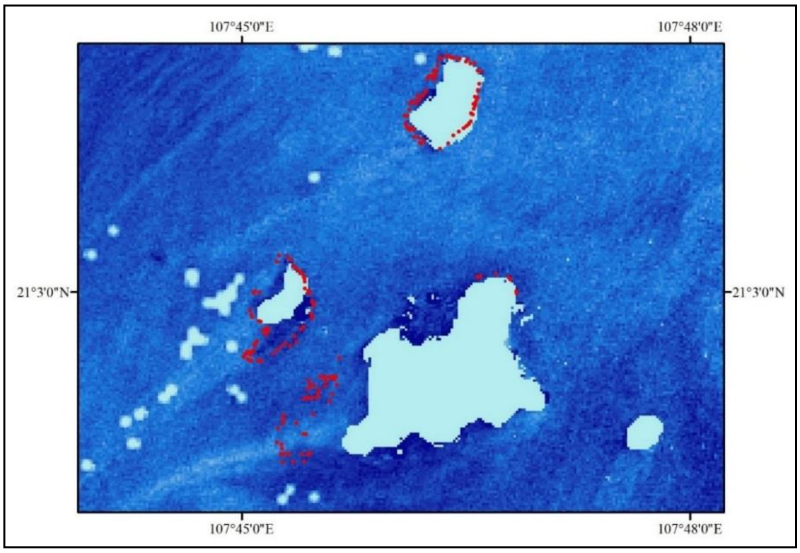


*Figure 7. Distribution of actual sampling points.*

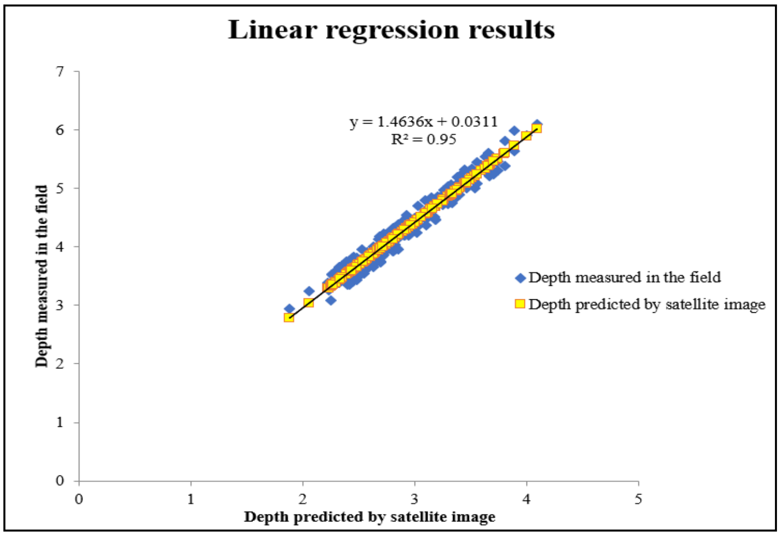


*Figure 8. Compare the results of depth determination from Sentinel-2 images and actual results.*

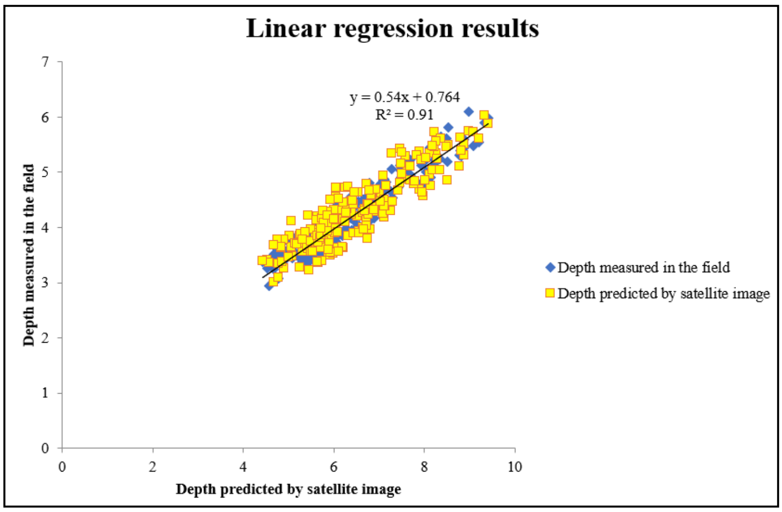


*Figure 9. Compare the results of depth determination from Landsat 8 images and actual results.*

Based on the regression models obtained above, research shows that Sentinel-2 image provides more effective depth prediction results than Landsat 8 data on the same study area. In addition, the results of the Sentinel-2 image and the Landsat 8 image have RMSEs of 0.145 m and 0.195 m. It shows that the regression model for the depth data estimated from the Sentinel-2 image is more correlated than the data estimated from the Landsat 8 image.

## 4. Conclusions

The study proposed an automated depth mapping methodology using surface reflection datasets calculated from Landsat 8 and Sentinel-2 satellite imagery data on the Google Earth Engine platform. The research method allows us to estimate shallow water depth at a fast speed and low cost. Moreover, the test results show that the method is capable of estimating the depth of the coastal area with high accuracy. The correlation values and root mean square error show that the Sentinel-2 image gives better prediction results than Landsat 8 image. Simultaneously, depth prediction results can assist policymakers in planning research and development of marine potential in a sustainable way.

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# LẬP BẢN ĐỒ ĐỘ SÂU KHU VỰC QUẦN ĐẢO CÔ TÔ, TỈNH QUẢNG NINH BẰNG ẢNH VỆ TINH SENTINEL-2 VÀ LANDSAT 8

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***Tóm tắt:*** *Nghiên cứu đề xuất phương pháp thành lập bản đồ độ sâu tự động dựa trên bộ dữ liệu phản xạ bề mặt của vệ tinh Landsat 8 và Sentinel-2 trong Google Earth Engine. Các tác giả tiến hành thử nghiệm trên khu vực quần đảo Cô Tô, huyện Cô Tô, tỉnh Quảng Ninh. Kết quả xử lý dữ liệu thu được bản đồ độ sâu ở vùng nước xung quanh quần đảo, qua kiểm tra với 199 điểm đo thực tế ngoài thực địa cho giá trị hệ số tương quan ($R^2$) là 0,95 với ảnh Sentinel-2 và 0,91 với ảnh Landsat 8. Bên cạnh đó, giá trị sai số trung phương (RMSE) thu được với dữ liệu hình ảnh Sentinel-2 và Landsat 8 lần lượt là 0,145 m và 0,195 m. Phương pháp bước đầu cho thấy tính tự động, hiệu quả và có kết quả tin cậy trong phục vụ thành lập bản đồ độ sâu trên vùng biển Việt Nam, đặc biệt là ở những khu vực ven bờ, ven quần đảo. Đồng thời, phương pháp còn hỗ trợ công tác theo dõi, cập nhật thường xuyên.*

**Từ khóa:** Bản đồ độ sâu; Landsat 8; Sentinel-2; Cô Tô; Google Earth Engine.

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