MAPPING REEF ZONATIONS OF THE ATOLLS IN TRUONG SA ISLANDS BY USING LANDSAT 80LI IMAGERY

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Abstract

The Truong Sa islands play an essential part in military, security and defense, and socioeconomic purposes. Truong Sa consists of many islands and atolls. However, the reef zonations or geomorphic zones of coral reefs of the atolls are poorly documented because of the absence of field measurement data, especially in disputed areas. The authors use Landsat 80LI satellite imagery and the Support vector machine (SVM) classification method to classify the atolls' reef zonation in the paper. The authors also experienced the DII index for bands 2, 3, 4 of the Landsat 80LI image to correct the water column in the pre-processing image step, which are the input data of the classification processing. The classification accuracy achieved 97.8% and 98.3%. The study area is at Toc Tan island and Thuyen Chai island.

Keywords: Reef zonations; Truong Sa islands; Landsat 80LI data; depth-invariance index.

1. Introduction

Vietnam is a country with a long coastline with many islands. In which coral reefs play an essential role in protecting ecosystems and the marine environment. Coral reefs are referred to as "tropical forests" on the seafloor because they are habitats for benthic and fish species [10]. Besides, coral reefs have a crucial role in military activities, especially atolls. All coral atolls are surrounded by reefs on both the ocean and lagoon sides of the islets. There is a significant natural obstacle in favor of the defenses. At low tide, the reefs create a perfectly flat cleared field for the defenders [20].

Remote sensing technology is currently an advanced technology that enables remote information collection. Many scientists have proposed to combine satellite imagery and field measurement data for monitoring coral reefs. Remote sensing data used in these studies are medium spatial resolution images such as Landsat [13, 17, 19], high-resolution images [6] such as SPOT, Sentinel-2, ASTER, and very high-resolution images such as IKONOS, QuickBird, UAV [14, 16]. Besides, the hyperspectral satellite images with high spectral resolution are used [11, 15]. Many classification methods have been proposed to distinguish coral reefs by remote sensing data. Classification

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methods include the object-based [12], or the pixel-based [4]. The research using remote sensing data to classify geomorphic zones in Truong Sa islands is currently limited. Dong et al., 2019 [7] has published the results of classifying geomorphic zones of the atolls in Truong Sa islands using multi-temporal Landsat data.

In Vietnam, the Institute of Oceanography's scientists has also conducted research on coral reefs in coastal areas of Vietnam [1, 2]. The studies mainly determined coral reefs based on field measurement stations on the islands. Dien et al., 2012 [18] used satellite images and GIS data to determine the distribution of coral reefs in Nha Trang, and the coastal area of Ninh Thuan. The data included in GeoEye-1, IKONOS, QuickBird images and the classification method used the Mahalabonis Distance method with an accuracy of 79.5% and the Kappa coefficient of 0.7247. In the paper [18], the authors have used atmospheric correction images, PCA image and water column correction by DII (Depth-invariant index). Quang et al., 2015 [3] used the Landsat 80LI image established coral reef map of Ly Son island, Quang Ngai province with a classification accuracy of 94%, and the Kappa coefficient of 0.93.

In this paper, the authors proposed establishing the atolls Truong Sa islands' reef zonation mapping using Landsat 80LI data. SVM classification method was used to determine the reef's zonation based on the DII image of bands 2, 3, and 4 of Landsat 80LI imagery.

2. Study area and materials

2.1. Study area

Truong Sa islands (the Spratly Islands in English) are a collection of islands in the East Sea, Vietnam. However, the islands are in dispute at different countries between Brunei, Taiwan, Malaysia, the Philippines, China, and Vietnam [21]. Truong Sa islands are located from 6°12' to 12°00' North latitude and 111°30' to 117°20' East. Truong Sa islands are divided into three clusters of islands that have different sizes. The first cluster is a collection of entities in the Northern with a dense and uniform distribution. In the Eastern and Southeastern, there is the second cluster with a sparse and uniform distribution. The third cluster is in the South and Southwest of Truong Sa islands with scattered and unevenly distributed in size [23].

The study area is Toc Tan island (Figure 1b) and Thuyen Chai (Figure 1c), which are in the second cluster and the atolls of the Truong Sa islands [23]. Vietnam currently controls Toc Tan island and Thuyen Chai island and relies on it in Truong Sa town, Truong Sa district, Khanh Hoa province.



Figure 1. The study area: (a) Location of the study area; (b) Toc Tan island in the RGB composite image; (c) Thuyen Chai island in the RGB composite image.

2.2. Material data and pre-processing

According to Green et al., 1996 [9], the level of habitat detail and ability to classify coral reefs from satellite imagery depends mainly on the spectral and spatial resolution. Landsat imagery is free data, has a medium spatial resolution of 30m. The Landsat data is suitable for bathymetry and geomorphic mapping [5]. The material data is Landsat 80LI imagery with the characteristics in Table 1.

Parameters	Descriptions			
Landsat_scene ID	LC81200542019224LGN00			
Date	12/08/2019 with UTC 02:43:51			
Path/Row	120/54			
Cloud_cover	6.8%			
Bith depth	16 bits			
Projected	UTM/WGS 84			
Level	Level 1			

Table 1. The characteristic of material data

Landsat 80LI data requires pre-processing image. The pre-processing consists of three main steps: (1) Convert DN (Digital number) to TOA (Top of Atmosphere); (2) Atmospheric correction by using DOS (Dark Object Substraction) method; (3) Correct the water column by DII (Depth-Invariance Index) coefficient.

Atmospheric correction is the first pre-processing step in the analysis of satellite images. In this article, we applied DOS (Dark Object Substraction) method for correcting atmospheric effection of TOA reflectance data because it is suitable for the ocean.

Secondly, the data need to correct the water column. The water column correction method is to transform the surface reflectance value to the benthic reflectance value. In the fact that, the light penetrates the water and the water column often is corrected by DII index (Depth-Invariance Index). The DII index depends on the bottom type of the ocean. The intensity value in the image decreases exponentially as the depth increases [8] and is calculated by the DII index as the following equation:

$$DII = \ln(L_i) - \binom{k_i}{k_j} \times \ln(L_j)$$
⁽¹⁾

where L_i is the surface reflectance of the benthic on the sea with band *i*; L_j is the surface reflectance of the benthic on the sea with the band *j*; k_i and k_j are the light intensity reduction factors of band *i* and band *j*.

The reduction coefficient $\binom{k_i}{k_j}$ depends on the wavelength of the bands and the

clarity of the water [24]. The gradient of the line is often determined based on field measurements and linear regression methods. But it is difficult to determine the corresponding light intensity attenuation coefficient on the Landsat 80LI image in Truong Sa islands. Therefore, the authors proposed to apply the attenuation coefficient determined in the Ly Son island area, Quang Nam province [3]. The DII of the pairs of Landsat 80LI bands is as follows:

$$DII_{34} = \ln(L3) - 1.044 \ln(L4)$$

$$DII_{23} = \ln(L2) - 0.586 \ln(L3)$$

$$DII_{24} = \ln(L2) - 0.68 \ln(L4)$$
(2)

where *L*2, *L*3, *L*4 are the surface reflectance of the benthic on the sea with band 2, band 3 and band 4 of Landsat 80LI imagery.

The DII of Ly Son island is proposed to apply for the atolls in Truong Sa because of the following principal reasons: (1) Ly Son Island's bottom material is mainly coral mortality and seagrass or sand, similar to the bottom of the atolls' shallow waters in Truong Sa area; (2) The depth of the study area of Ly Son is from 5m to 20m; (3) The clarity of seawater at Thuyen Chai island is equivalent to Class I. Besides, seawater's clarity at Ly Son and Toc Tan island is equivalent to class II because of the Toc Tan area's construction activities at the image acquisition time; (4) The DII of Ly Son island was determined based on field measurements and Landsat 80LI imagery. The results of water column correction are shown in Figure 2.



Figure 2. (a) and (c) The RGB composite Landsat 80LI images; (b) and (d) The RGB composite of DII₃₄, DII₂₃, DII₂₄ of Toc Tan island and Thuyen Chai island

3. Methodology

3.1. Mapping reef zonations of the atolls by Landsat 80LI imagery

Figure 3 shows the flowchart of mapping reef zonations of the atolls using Landsat 80LI imagery. The processing includes two main parts such as (1) The preprocessing images; (2) Classification image by using supervised classification method. In this study, the authors applied the SVM (Support Vector Machine) classification method to classify reef zonations of the atolls using the corrected water column images (Figure 2b and 2d).

The reef zonations or the coral reef geomorphology are interpreted by the reflectance of coral reefs in satellite images. These reflectances depend mainly on bathymetry, bands, and water level [7]. Based on the research results at Truong Sa islands by Dong et al., 2019 [7], the reef zonation of the atoll [22] and interpretation by

expert knowledge on high resolution images in Google Earth then we categorized the coral reefs of the study area into four geomorphic zones such as Back reef, Fore Reef, Reef crest and Reef Flat (Figure 4). The back reef is an area that slopes into a lagoon. The back reef is often shallow and more protected from wave action. The fore reef or reef front is found at the furthest distance from shore. The reef crest is the highest point of the reef. The reef crest breaks waves and receives the fullest impact of wave energy. During low tide, reef crests can be exposed to air. The reef flat is an area that is protected from wave action. The reef flat can extend from the meter to kilometers, and the depth can range from centimeters to a meter [22].



Figure 3. The flowchart of mapping the distribution of reefs zones by using Landsat 80LI



Figure 4. Reef zonation of atoll [22]

3.2. Classification results

The classification results of the reef zonations of Toc Tan island and Thuyen Chai island are shown on Figure 5.



Figure 5. The reef zonations map (a) Toc Tan island; (b) Thuyen Chai island; (c) and (d) Areas of Toc Tan and Thuyen Chai (km²)

The assessment of classification accuracy is shown in Table 2 and Table 3. The classification accuracy of Toc Tan island is 97.78%, and that of Thuyen Chai island is 98.34%. In Tables 2 and 3, we can show the classification accuracy of cloud object. However, we have merged the cloud and ocean object as ocean object in Figure 5a and 5b.

it	Ground truth by ROI (pixels)								
Classification by Landsa 80LI		1	2	3	4	5	6	Total	
	1	219	0	0	0	0	0	219	
	2	2	95	0	0	0	0	97	
	3	0	0	132	6	0	2	140	
	4	0	0	1	314	0	0	315	
	5	0	0	0	0	1246	33	1279	
	6	0	0	0	0	7	239	246	
	Total	221	95	133	320	1253	274	2296	
Overal accuracy = 97.78%									
Kappa index = 0.9658									

Table 2. The assessment of the classification accuracy in Toc Tan island

	Ground truth by ROI (pixels)								
sification by Landsat 80LI		1	2	3	4	5	6	Total	
	1	719	4	0	5	0	0	728	
	2	3	106	0	0	0	0	109	
	3	0	0	279	17	0	0	296	
	4	1	0	22	457	0	0	480	
	5	0	0	0	0	845	0	845	
Clas	6	0	0	0	7	2	1201	1210	
Ŭ	Total	723	110	301	486	847	1201	3668	
Overal accuracy = 98.34%									
Kappa index = 0.9785									

Table 3. The assessment of the classification accuracy in Thuyen Chai island

1- Back Reef; 2- Fore Reef; 3- Reef Crest; 4- Reef Flat; 5- Ocean; 6- Cloud

The atmospheric and signal attenuation in the water body affects the identification and classification accuracy of geomorphic zones by optical images. In particular, it is difficult to determine the DII index of the wavelength on satellite images in the Truong Sa area, so that the bottom affection has not been fully corrected. Besides, the classification samples of geomorphic zones in atolls islands often are chosen based on expert knowledge.

Figures 5c and 5d show the distribution area of the four geomorphic zones on Toc Tan island and Thuyen Chai island. Coral reef areas were assessed based on the count of pixel numbers, and we did not consider the area distribution caused by variation in the slope of the underwater topography. In Figures 5c and 5d, the Thuyen Chai is in the form of a closed atoll with open lagoons in the middle, so the Back Reef area is as large as 21 km². Meanwhile, the Back Reef area of Toc Tan is only 8.4 km² because Toc Tan is on open atoll, and the lagoon is affected by sea waves, and there is not much sedimentation of coral sand and rocks. The Back reef area is underwater parts, so that is suitable for parking boats. Reef Crest and Reef Flat are the parts that often exposed the air at low tide and a shallow depth, so it is possible to construct the above structures.

4. Conclusion

In conclusion, the article's method is proposed to map geomorphic zones of the atoll by using Landsat 80LI. The DII index of Ly Son island [3], where the bathymetry and seawater conditions are similar to the study area, is applied for water column correction correspondings to pairs of band 3 and 4, band 2 and 3, band 2 and 4 of Landsat 80LI in Truong Sa islands. Classification accuracy geomorphic zones of coral reefs depend on bathymetric, bands, water level, and expert knowledge when

interpreting satellite images. Truong Sa is a disputed area, so the field measurement data of the distribution habitat detail and geomorphological characteristics of coral reefs in the atolls are limited. The research results in this article help supplement information and remote sensing application in researching atolls of Truong Sa islands. In the future, the combination of field data, Landsat 80LI, and other sensors (e.g., Sentinel-2 satellite image) can provide more information of Truong Sa islands.

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THÀNH LẬP BẢN ĐỒ CÁC VÙNG SAN HÔ TRÊN ĐẢO SAN HÔ VÒNG THUỘC QUẦN ĐẢO TRƯỜNG SA SỬ DỤNG TƯ LIỆU LANDSAT 80LI

Tóm tắt: Quần đảo Trường Sa đóng vai trò quan trọng về quân sự, an ninh, quốc phòng và kinh tế - xã hội. Trường Sa gồm nhiều đảo nổi và đảo san hô vòng. Tuy nhiên, các vùng san hô hay vùng địa mạo rạn san hô của các đảo san hô vòng được công bố rất ít vì thiếu dữ liệu đo đạc thực địa, đặc biệt là ở các khu vực có tranh chấp. Trong bài báo, các tác giả sử dụng ảnh vệ tinh Landsat 80LI và phương pháp SVM (Support Vector Machine) để phân loại các vùng san hô trên đảo san hô vòng. Các tác giả cũng đã thử nghiệm hệ số bất biến độ sâu DII (Depth-Invariance Index) cho các kênh ảnh 2, 3, 4 của tư liệu Landsat 80LI để hiệu chỉnh cột nước ở bước tiền xử lý ảnh. Đây cũng là tư liệu ảnh đầu vào của quá trình phân loại ảnh. Độ chính xác phân loại đạt 97,8% và 98,3%. Khu vực nghiên cứu tại đảo Tốc Tan và đảo Thuyền Chài thuộc quần đảo Trường Sa.

Từ khóa: Vùng san hô; quần đảo Trường Sa; dữ liệu Landsat 80LI; chỉ số bất biến độ sâu (DII).

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