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Automatic extraction of coastline based on Google Earth engine

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ABSTRACT

Traditional remote sensing image-based coastline extraction is limited by data volume and processing speed, and the extracted coastline is susceptible to noise. Therefore, this paper proposes a method based on the Google Earth Engine geospatial platform, which combines threshold segmentation, the Otsu method, and morphological algorithms. First, remote sensing images are preprocessed on the platform, and the Normalized Difference Water Index (NDWI) is calculated. Then, the Otsu method is used to calculate the NDWI threshold for water-land segmentation, resulting in a binary water-land image. Next, morphological methods are employed to remove noise points, fill holes, and extract the coastline. The proposed method was tested using Hainan Island based on synthetic images from August 2021, and the average accuracy of land-water segmentation reached 98.49%. The results demonstrate that this method can accurately extract coastlines and significantly improve extraction efficiency. This research method provides a reference for the automatic extraction of coastlines over large areas and long time series.

KEYWORDS

Cloud Computing; Coastline Extraction; Morphological Algorithm.

1. INTRODUCTION

The coastline refers to the demarcation line between land and sea, typically defined as the average high tide line over several years . It constitutes a distinctive feature of the coastal zone system and holds significant ecological services and economic value. Subject to the dual influence of anthropogenic and natural factors, the coastline remains in a state of continuous change. Consequently, the rapid and precise determination of the coastline plays a pivotal role in the management of coastal resources, rational planning, and the sustainable development of coastal areas [2-7].

Traditional methods for measuring coastlines have several limitations, including challenges posed by complex coastal topography, difficulties in fieldwork, and substantial outdoor labor requirements. However, with the rapid advancement of remote sensing technology, the extraction of coastlines from remote sensing imagery has emerged as a prominent research focus. In the research involving the extraction of coastlines from remote sensing imagery, the primary methods include threshold segmentation, edge detection, region growing, and morphological approaches . The threshold segmentation method is simple to implement and easy to use, but it requires repeated experimentation to obtain the optimal threshold, and is easily affected by spectral similarity features, resulting in low accuracy in extracting coastline. So it is generally combined with other methods for feature extraction, which can achieve better results than a single threshold segmentation method [9, 10]. Edge detection methods are effective in extracting coastline edges, with the Canny algorithm being one of the most widely used among all edge detection techniques. This method performs especially well for smooth and simple coastlines, but it has lower noise resistance and may encounter interruptions in the extracted coastline [11, 12]. The region-growing method involves merging pixels with neighboring pixels based on their similarity to form a cluster. This method is relatively mature but is susceptible to noise interference. In regions with complex terrain, it may also result in distortions [13-15]. Morphological algorithms are primarily used in combination with other methods to remove noise in coastal line extraction. Traditional remote sensing image processing is constrained by data volume and processing speed. However, the development of remote sensing cloud computing technology and the emergence of cloud computing platforms have provided new opportunities for processing vast amounts of remote sensing data and conducting long time-series analysis. This has transformed the traditional mode of remote sensing data processing and analysis, significantly improving computational efficiency . Currently, Google Earth Engine (GEE) is one of the most widely used geographic cloud platforms. In research based on the GEE platform, both domestic and international scholars have conducted water body recognition studies from various perspectives. For example, PEKEL J.F. and others used GEE to analyze the changes in global surface water from 1984 to 2015. Additionally, researchers like Peng Yanfei employed GEE to extract and study the area changes of the Boseten Lake. Tiantian Gong and colleagues used GEE to extract data on lakes in Wuhan, China, from 1987 to 2019 and investigated their spatiotemporal changes. While research on water body extraction, particularly for surface water and lakes, using the GEE platform is relatively mature, there has been less focus on coastline extraction.

Therefore, building upon the research in water body extraction, this study proposes a remote sensing image coastline extraction method based on Google Earth Engine (GEE). This method combines threshold segmentation, the Otsu method, and morphological algorithms. It facilitates the extraction of coastlines from high-resolution images over large areas and allows for the analysis of long time series, greatly enhancing computational efficiency.

2. OVERVIEW OF THE STUDY AREA

Hainan Province is located at the southernmost tip of China, with its geographical coordinates ranging between approximately 108°37′ to 111°03′ longitude east and 18°10′ to 20°10′ latitude north. Hainan has a tropical monsoon climate characterized by warm temperatures throughout the year and abundant rainfall. As a base for the development and utilization of resources in the South China Sea, Hainan Province has a unique historical heritage and plays an irreplaceable role due to its strategic location and significance, particularly in the construction of the "Belt and Road Initiative." It also carries a crucial responsibility in China's strategy in the South China Sea. Hainan Province boasts three major ports: Haikou Port, Yangpu Port, and Sanya Port. These large ports are vital for the province's foreign trade and have significant implications for safeguarding trade at the ports and promoting the sustainable development of the coastal areas. Studying the coastline of Hainan Province is of great significance for ensuring port trade security and facilitating the sustainable development of the coastal zone.

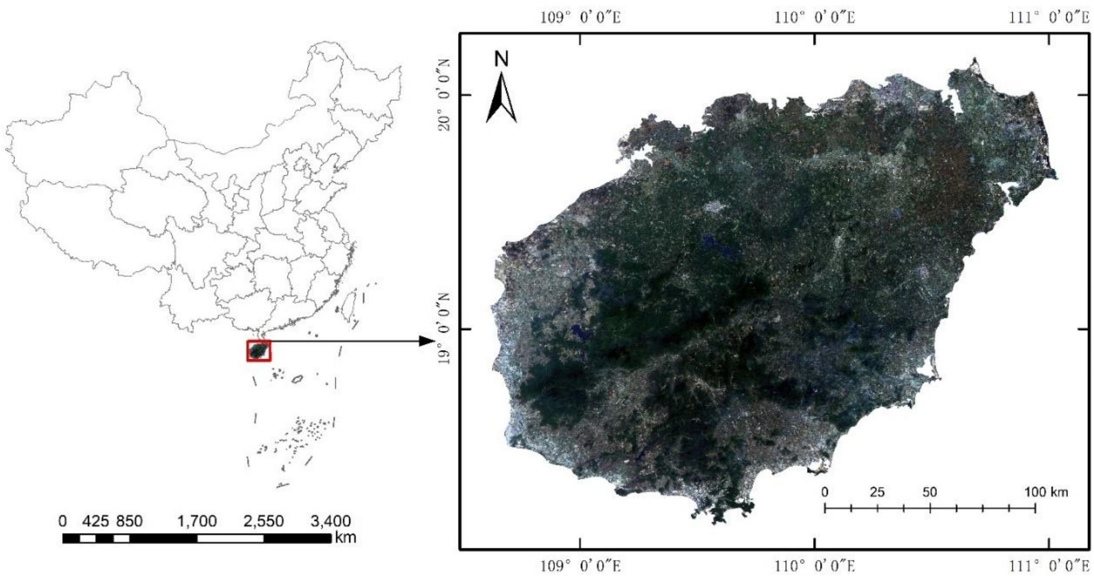


Figure 1. Hainan research area

3. RESEARCH DATA AND METHODOLOGY

3.1. Data

3.1.1 Remote sensing data

The remote sensing imagery utilized in this study comprises Sentinel-2 Level-1C images captured between January 2021 and August 2021. These images have undergone orthorectification and sub-pixel geometric correction. The spectral band information is summarized in Table 1.

Table 1. Sentinel-2 band information table

Name	Scale	Pixel Size	Wavelength	Description
B1	0.0001	60 m	443.9nm (S2A) / 442.3nm (S2B)	Aerosols
B2	0.0001	10 m	496.6nm (S2A) / 492.1nm (S2B)	Blue
B3	0.0001	10 m	560nm (S2A) / 559nm (S2B)	Green
B4	0.0001	10 m	664.5nm (S2A) / 665nm (S2B)	Red
B5	0.0001	20 m	703.9nm (S2A) / 703.8nm (S2B)	Red Edge 1
B6	0.0001	20 m	740.2nm (S2A) / 739.1nm (S2B)	Red Edge 2
B7	0.0001	20 m	782.5nm (S2A) / 779.7nm (S2B)	Red Edge 3
B8	0.0001	10 m	835.1nm (S2A) / 833nm (S2B)	NIR
B8A	0.0001	20 m	864.8nm (S2A) / 864nm (S2B)	Red Edge 4
B9	0.0001	60 m	945nm (S2A) / 943.2nm (S2B)	Water vapor
B10	0.0001	60 m	1373.5nm (S2A) / 1376.9nm (S2B)	Cirrus
B11	0.0001	20 m	1613.7nm (S2A) / 1610.4nm (S2B)	SWIR 1
B12	0.0001	20 m	2202.4nm (S2A) / 2185.7nm (S2B)	SWIR 2
QA10		10 m		Always empty
QA20		20 m		Always empty
QA60		60 m		Cloud mask

3.1.2 DEM data

The digital elevation model (DEM) data utilized in this study is derived from the Shuttle Radar Topography Mission (SRTM) dataset, a near-global digital elevation model jointly produced by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA) through radar interferometry. The SRTM Version 3 (SRTM Plus) product, provided by NASA's Jet Propulsion Laboratory (JPL), offers a spatial resolution of 1 arc-second, approximately 30 meters. The choice of the SRTM digital elevation data was made due to its higher accuracy compared to other versions of DEM data. This is attributed to the fact that the SRTM data utilized open-source data sources (ASTER GDEM2, GMTED2010, and NED) to fill in data gaps, as opposed to other DEM datasets that relied on commercial data sources, which may contain blank areas.

3.2. Methodology

3.2.1 The Normalized Difference Water Index (NDWI) combined with a thresholding technique.

The Normalized Difference Water Index (NDWI) is a remote sensing index used to highlight water features within imagery through a specific spectral band normalization and differencing process. NDWI was introduced by McFeeters in 1996 and is based on the normalized ratio of the green band to the near-infrared band. In this paper, it is employed for the purpose of water feature identification within the imagery, and it has demonstrated favorable performance. Its mathematical expression is as follows:

$$NDWI = \frac{P(Green) - P(NIR)}{P(Green) + P(NIR)} \tag{1}$$

Threshold segmentation is a technique that utilizes the variations in grayscale values of each pixel in an image. It defines one or more thresholds to partition the image into different classes, where pixels within each class exhibit grayscale values within a specified range and correspond to distinct objects or features.

3.2.2 OTSU algorithm

The OTSU algorithm, also known as Otsu's method or the maximum between-class variance method, was introduced by Otsu in 1979. It is considered to be the optimal algorithm for threshold selection in image segmentation. It is robust against variations in image contrast and brightness and offers a straightforward computational approach. Consequently, it has found extensive applications in the field of digital image processing. To find the optimal threshold, the problem is defined as follows:

Assuming that an image consists of a total of m pixels, where m_1 pixels have grayscale values less than the threshold, and m_2 pixels have grayscale values greater than or equal to the threshold($m_1 + m_2 = m$). S_1 and S_2 represent the proportions of these two types of pixels, respectively. The average and variance of grayscale values for all pixels with values less than the threshold are denoted as μ_1 and σ_1, while the average and variance for all pixels with values greater than or equal to the threshold are denoted as μ_2 and σ_2. Therefore, it can be derived that:

$$Intra - class\ variation = S_1\sigma_1^2 + S_2\sigma_2^2 \tag{2}$$

$$Inter - class\ variation = S_1S_2(\mu_1 - \mu_2)^2 \tag{3}$$

To find the appropriate threshold, one can aim to minimize intra-class differences or maximize inter-class differences. In this paper, the threshold for the NDWI is determined by calculating the maximum inter-class difference, which is used to segment water and land areas.

3.2.3 Morphological algorithms

Mathematical morphology is a field of image analysis built on the foundations of lattice theory and topology. It serves as the fundamental theory for mathematical morphology in image processing. In the context of image processing, morphology can be categorized into binary morphology and grayscale morphology. It is commonly applied in various image processing tasks such as image segmentation, thinning, skeletonization, edge detection, shape analysis, corner detection, watershed algorithm, and more. The fundamental operations in morphology are erosion and dilation, typically applied to binary images. In this paper, morphological operations are employed to effectively remove noise in shoreline extraction.

4. RESULTS AND DISCUSSION

4.1. The results of coastline extraction

Before coastline extraction, image preprocessing is required, which primarily involves cloud removal and image compositing. Firstly, cloud removal is performed, where data with a cloud cover exceeding 20% are filtered out. A cloud removal process is executed using Sentinel-2's quality assessment band 'QA60,' which contains information about both Opaque clouds and Cirrus clouds. These clouds are masked out using the mask function to achieve cloud removal. In this study, a total of 502 remote sensing images from January 2021 to August 2021 within a rectangular region encompassing Hainan Province were selected for compositing. The composite image is created by calculating the median value for each pixel across all matching bands in the stack. The resulting composite image is shown in Figure 3(a).

By calculating the Normalized Difference Water Index (NDWI), which is the normalized ratio of the green band to the near-infrared band, water features in the image can be highlighted, as shown in Figure 3(b). To obtain the NDWI threshold for water-land segmentation, statistical analysis of NDWI values within the defined region is performed, resulting in the NDWI histogram depicted in Figure 2. The two peaks in the histogram can be roughly categorized as land and water, with the threshold expected to lie between these peaks. To obtain a relatively accurate threshold, the Otsu method is employed to calculate the inter-class variance, maximizing it to determine the threshold for subsequent water-land segmentation. Through the Otsu method, the threshold for the NDWI image is determined as 0.048. Using threshold segmentation, areas with NDWI values greater than the threshold are classified as land (assigned a value of 0), while areas with values less than the threshold are classified as water (assigned a value of 1). The resulting binary image is shown in Figure 3(c).

From the binary image, it is evident that there are inland rivers and islands, which could introduce noise in the subsequent vectorization process and affect the accuracy of coastline extraction. Therefore, this paper employs dilation and erosion operations from mathematical morphology to eliminate the impact of such noise. Initially, reverse buffering analysis is performed using DEM data to calculate the areas of ocean and land outside the coastal region. These areas are then used as mask data to eliminate the influence of inland water systems. Additionally, maximum island area thresholds (in pixels) are defined for both ocean and land, preventing the coastline extraction from including the coastlines of islands when processing the coastline of mainland China.Next, the number of connected neighboring pixels for each pixel is computed, enabling the removal of isolated islands. The resulting image, after the removal of isolated islands, is depicted in Figure 3(d). A comparison between the original binary image and the one after noise removal shows that the dilation and erosion operations from mathematical morphology effectively fill in gaps and remove noise.

After converting the raster image, following the removal of isolated islands, into vector format and specifying parameters such as the conversion area and resolution, you can obtain boundary information for the coastline. The extraction results are shown in Figure 4.

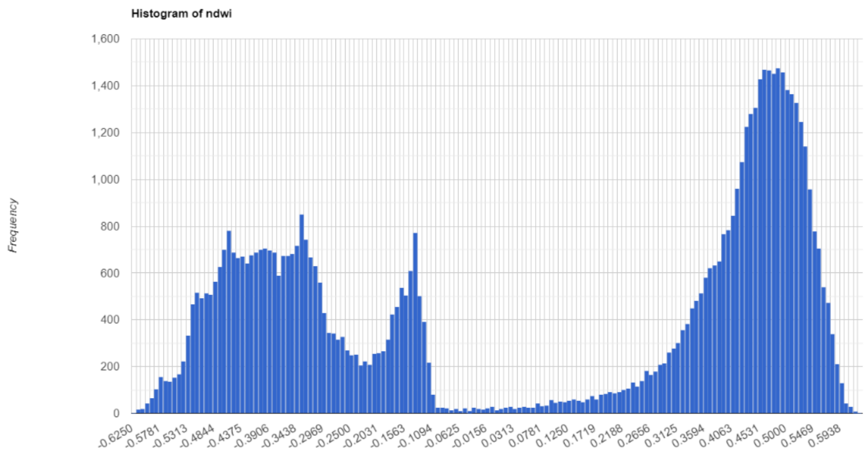
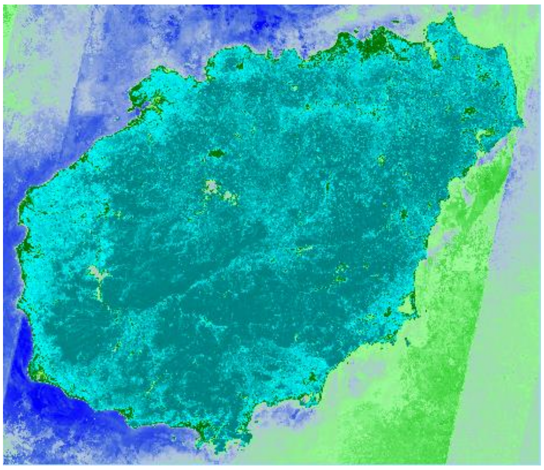


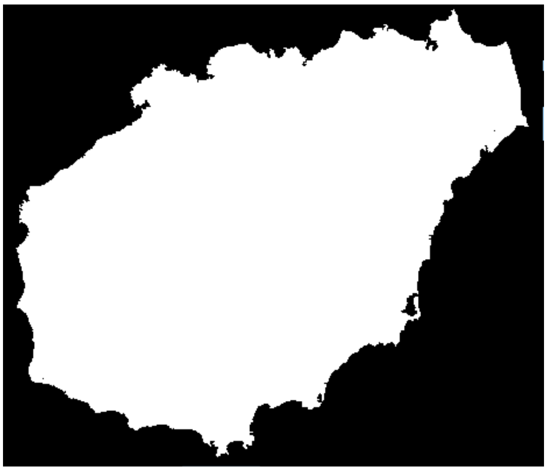
Figure 2. Histogram of NDWI

(a) Raw image after preprocessing



(b) NDWI images

(c) Image after binarization



(d) De-noised image

Figure 3. Intermediate process map of Coastline Extraction

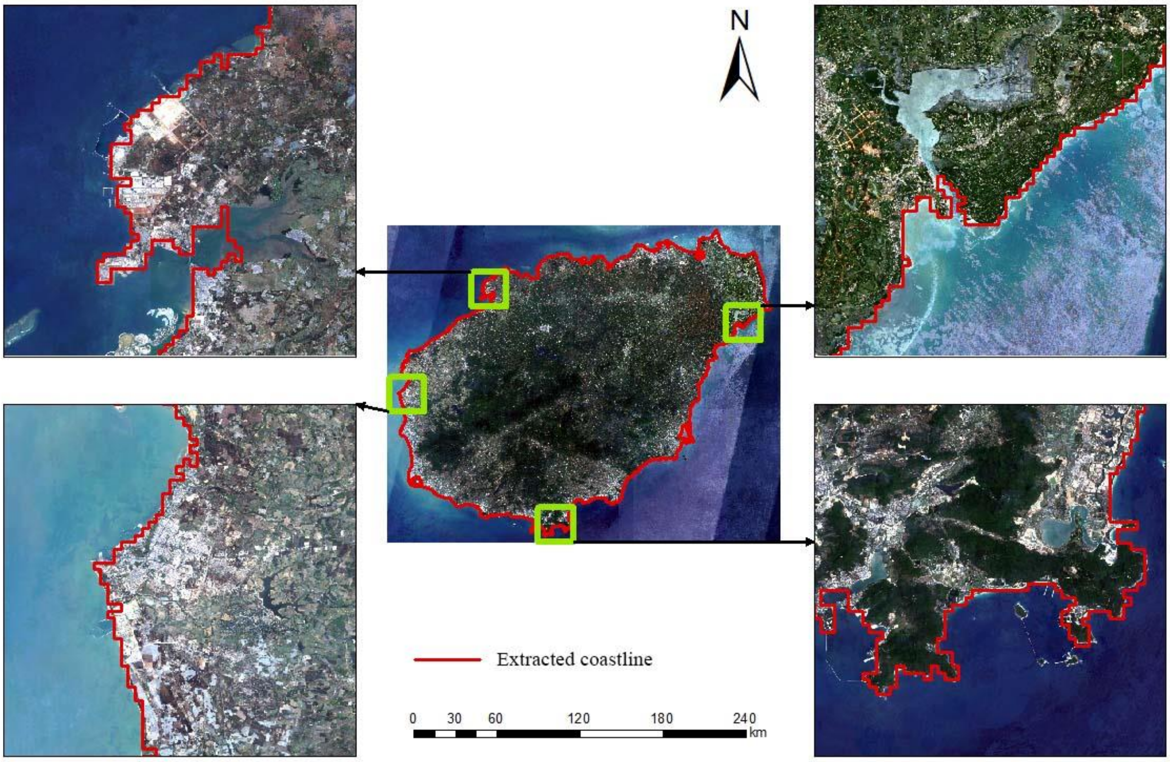


Figure 4. Coastline extraction result

4.2. Accuracy verification

To validate the accuracy of coastline extraction, the synthesized image mentioned earlier is used as the reference image. The reference coastline is obtained through visual interpretation. By comparing it with the extracted coastline, it can be observed that in relatively regular coastlines, such as rocky shorelines and man-made coastlines, the extracted coastline aligns well with the reference coastline, indicating high accuracy. However, in areas with relatively ambiguous coastlines, such as tidal flats, the extraction results may be less satisfactory. This is because during manual interpretation, the reference coastline for tidal flat areas is also challenging to determine accurately, which affects the accuracy assessment. Currently, the accuracy assessment of coastline extraction is primarily done through qualitative analysis using visual interpretation or through quantitative analysis by comparing the extracted coastline with a reference coastline. Quantitative analysis may involve calculating metrics such as average offset and root mean square error between the two coastlines . However, it is important to note that obtaining a reliable reference coastline can be challenging, and the accuracy assessment methods are to a large extent dependent on the quality of the reference coastline. Additionally, coastlines are dynamic and subject to change over time, making it difficult to ensure the accuracy of accuracy validation results.

Since this paper uses a threshold segmentation method combined with the Otsu algorithm for land-water segmentation, the accuracy of land-water separation largely represents the accuracy of coastline extraction. The paper conducts separate compositing for images from each of the 8 months and applies the same threshold as used for coastline extraction to perform binarization. Land areas are designated as 1, while ocean areas are designated as 0. The paper then calculates the average values of land and ocean regions for the 8 months. The results show that the accuracy for land is 97.75%, and since the extracted coastline also includes features like lakes and rivers within land areas, the overall accuracy is higher than 97.75%. Similarly, the accuracy for ocean regions is 99.24%. The overall average accuracy for land and ocean is 98.49%. These results demonstrate that the land-water segmentation achieves a high level of accuracy, reflecting the accuracy of coastline extraction. The extracted coastline exhibits favorable results, validating the suitability of the algorithm for coastline extraction.

The coastline automatic discrimination algorithm proposed in this paper has been applied to delineate water boundaries. The resulting coastline exhibits a high level of accuracy and completeness. However, there are certain issues that require further refinement. The method used for coastline extraction does not account for the phenomenon of tidal fluctuations affecting the actual coastline. Physical coastlines are influenced by factors such as time and season. For instance, muddy shorelines are influenced by tides, necessitating tidal correction for elevation data to obtain more accurate coastline positions. Moreover, variations in the selection of image acquisition times can lead to differences in the extracted coastline.

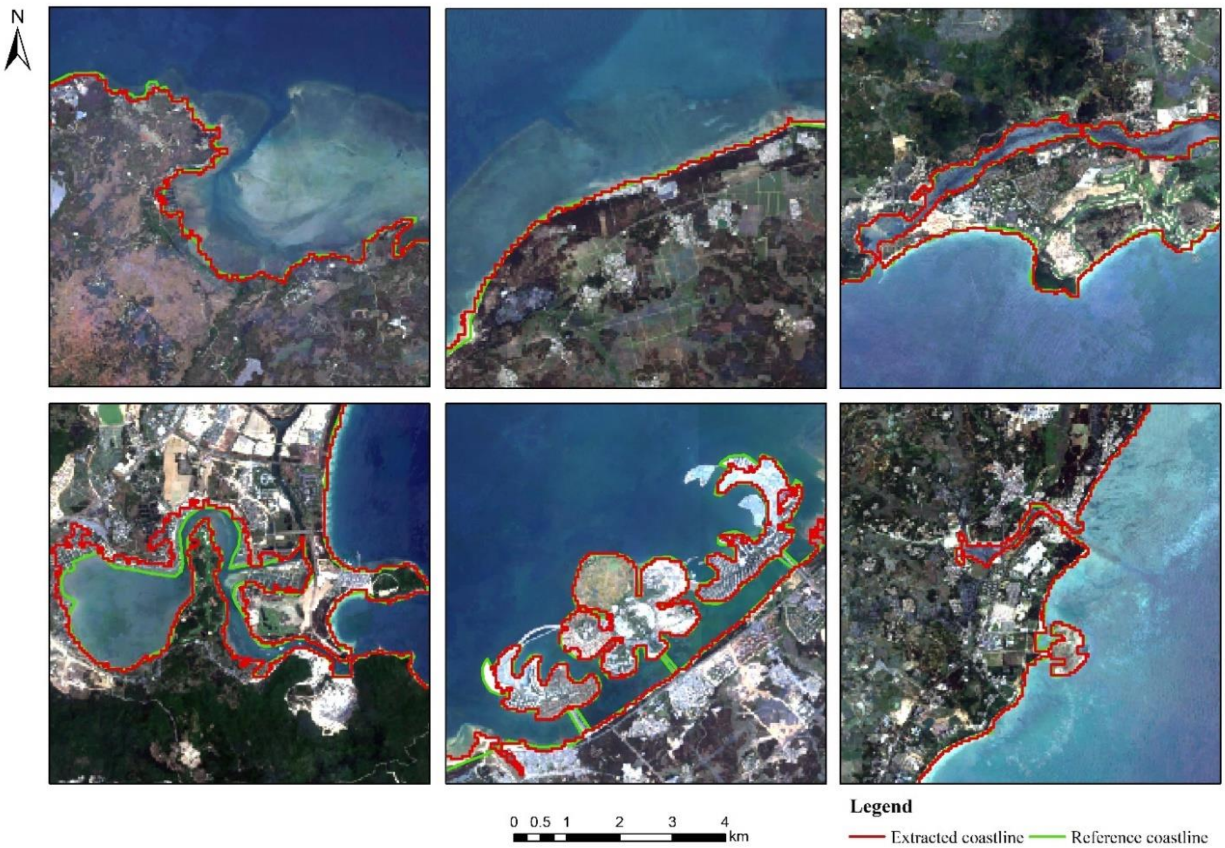


Figure 5. Comparison map of extracted coastline and reference coastline

5. CONCLUSION

This paper is based on a geospatial cloud platform, retrieving multiple Sentinel-2A images from different time periods. It employs a combined approach of threshold segmentation, the Otsu method, and morphological algorithms for coastline extraction. Taking into consideration the advantages of the Normalized Difference Water Index (NDWI) in land-water segmentation, NDWI imagery is used as input data, leveraging the spectral characteristics of the green and near-infrared bands, to extract the coastline of Hainan Province. A comprehensive analysis of the methods employed in this study leads to the following conclusions: (1) Experimental validation confirms that this paper's methodology effectively extracts the distribution of coastlines from satellite imagery. The resulting coastline images accurately represent coastal distribution. The extracted coastlines are linear and continuous, demonstrating their suitability for large-scale and long-term coastal extraction. (2) The extraction methodology outlined in this paper is characterized by clear steps and user-friendly operations. It efficiently eliminates the labor-intensive procedures associated with coastline extraction, reducing human-induced errors. This approach is proven to be an effective method for coastline extraction, with broad practical utility. (3) The remote sensing coastline extraction method developed in this paper, combining water indices with threshold segmentation, the Otsu algorithm, and morphological operations, can serve as a valuable reference for related research.

Utilizing geospatial cloud computing platforms like GEE for the processing and retrieval of remote sensing big data can significantly reduce storage space requirements, data transfer times, and computation durations. This enables researchers and policymakers to escape the dilemma of "rich data but poor information," allowing them to focus more on addressing scientific questions and formulating scientific policies. Consequently, this can enhance the level of scientific and technological management in the field of land and natural resources, contributing to China's sustainable development initiatives.

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