Research on the Change of Coastline on the South Coast of Hangzhou Bay Based on Multi-temporal Remote Sensing Images

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Abstract. Coastline is an important geographic background for each coastal area, and dynamic monitoring of coastlines is beneficial to coastal natural protection and further coastal construction and development. Based on the Landsat8 data and Sentinel-2 data from 2014 to 2019, this paper uses a method combining regional growth and edge detection to analyze the Cixi section's coastline changes on the south bank of Hangzhou Bay. Firstly, the multi-source remote sensing data is preprocessed, and then the MNDWI value of each image is calculated. Then, each image is processed into a binary image by a regional growth algorithm. Eventually, we realize the coastline segmentation by the Canny operator of edge detection. The research represents that the coastline of the south coast of Hangzhou Bay moves toward the ocean year by year, and the length of the coastline generally decreases. The analysis may be caused by human-made activities in Hangzhou Bay Area in recent years, such as river cut-offs and urban construction. The research in this paper provides a reference for the protection of natural coastlines and human-made coastlines.

1. Introduction

Since the reform and opening up, the eastern coastal area has become an important support for the national economy's rapid growth under its unique location advantages. While creating enormous economic and social benefits, it also changed the natural coastal pattern along Hangzhou Bay, causing tremendous changes in the coastal zone, imbalances in the marine ecosystem, and triggering a series of severe environmental disasters. Therefore, accurately extracting and timely grasping the dynamic change information of China's coastline and reclamation, and in-depth study of coastline changes and reclamation evolution process, is of great practical significance for promoting the sustainable development of the eastern coastal area and better realizing the national marine economic strategy.

The coastline refers to the boundary between the sea and the land. As a coastal country, the economic and strategic significance of the coastline cannot be underestimated. Therefore, the importance of coastline dynamic extraction is self-evident. However, affected by different factors, such as crustal movement, seawater erosion, and sediment accumulation, the coastline's location will change with the year. Therefore, the coastline location is extremely dynamic, which is not convenient for manual
extraction in the field. Remote sensing technology provides a large-scale, high-precision extraction scheme, which is widely used.

Many scholars at home and abroad have carried out many research work in the remote sensing analysis of coastline changes. Solomon [1] used aerial images to obtain coastline information of Beaufort Sea area and McKenney Delta and studied coastline changes; Zhu Junfeng [2] used multi-source and multi-temporal remote sensing images such as TM, ETM+, and ALOS to conduct remote sensing survey and evolution analysis of the Pearl River Delta coastline in 1998, 2003 and 2008.

This paper uses related software to perform threshold segmentation and boundary extraction on the Cixi section of the coastline on the south coast of Hangzhou Bay from 2014 to 2019 with the regional growth and edge detection method, and utilizes Sentinel-2 data (10m resolution) to extract the coastline for comparative analysis manually.

2. Research area and data information

2.1. Research area
This paper takes Hangzhou Bay as the study area and selects explicitly the southern coastal zone for the experiment, which is located between 120°52´ E~121°04´ E, 30°9´ N~30°18´ N, as shown in Figure 1. Hangzhou Bay is located on the southeast coast of China, between Shanghai and Zhejiang. It is the main throat connecting the two places. The terrain of Hangzhou Bay is generally flat, with an average water depth of about 11 meters. The water depth gradually increases from south to north and from west to east. The coasts are mostly marine silty clay plains, and some are bedrock coasts composed of volcanic rock and granite. The north and south banks have been subjected to erosion and siltation for a long time. In recent years, the development of Hangzhou Bay bridge construction and other projects has continued to rise. Therefore, studying the coastline’s changing laws on the south coast of Hangzhou Bay is of great significance.

![Fig 1. Research Area](image)

2.2. Data source and preprocessing procedure
Landsat-8 is the same as Landsat 1-7 in terms of spatial resolution and spectral characteristics. The satellite has a total of 11 bands. The spatial resolution of bands 1-7, 9-11 is 30 meters, and band 8 is 15 meters. With the resolution of the panchromatic band, the satellite can achieve global coverage every 16 days. The OLI land imager has nine bands, and the imaging width is 185×185km. Compared with the ETM sensor on the Landsat-7, the OLI land imager has made the following adjustments: 1. The band range of Band 5 is adjusted to 0.845-0.885 μm, excluding the influence of water vapor absorption at 0.825 μm. 2. Band 8 full color The band range is narrow so that vegetation and non-vegetation areas can be better distinguished. 3. Two new bands are added. The Band 1 blue band (0.433–0.453 μm) is mainly
used for coastal observation, and Band 9 shortwave infrared band (1.360–1.390 μm) is used for cloud detection.

A total of 7 periods of image data are collected in this study: Seven scenes of Landsat8 OLI image (2014-2019) and one scene of Sentinel-2 image (2020). The preprocessing work such as radiation calibration and atmospheric correction is carried out on each period's images, and the expected results are achieved. The preprocessing steps are as follows:

Firstly, it was obtained multi-source remote sensing data; (2) then perform radiation calibration to eliminate the influence of the sensor platform; (3) then perform atmospheric correction to eliminate the influence of the atmosphere; (4) finally use MNDWI for image enhancement.

| Image number | Imaging time | Spatial resolution/m | Platform     |
|--------------|--------------|----------------------|--------------|
| 1            | 2014.10.03   | 30                   | Landsat8 OLI |
| 2            | 2015.03.12   | 30                   | Landsat8 OLI |
| 3            | 2016.01.26   | 30                   | Landsat8 OLI |
| 4            | 2017.04.02   | 30                   | Landsat8 OLI |
| 5            | 2018.01.15   | 30                   | Landsat8 OLI |
| 6            | 2019.04.08   | 30                   | Landsat8 OLI |
| 7            | 2020.08.16   | 30                   | Landsat8 OLI |
| 8            | 2020.02.23   | 10                   | Sentinel-2   |

3. Research method

At present, the methods for remote sensing extraction of coastline at home and abroad include edge detection, wavelet analysis, density segmentation, etc. This paper uses multi-temporal remote sensing data sources to extract coastlines using the regional growth method and Canny operator edge detection to realize coastline transition analysis.

The overall process of this paper is shown in Figure 2, which mainly includes two parts. One is to extract coastlines using automatic extraction algorithms. First, it is used MNDWI to highlight water information. Then, the region growing algorithm forms a binary image. Furthermore, it is used the Canny operator to detect the edge of the binary image. Finally, the results of multiple coastline periods are obtained. The second is to use manual interpretation to extract coastlines for accuracy verification.

3.1. Calculation of MNDWI

The spectral difference of the ground objects in the original image after preprocessing is not significant. If used directly, it will easily affect the binary image segmentation in the later stage. Therefore, the significant indexes must be used to highlight the image water information.

Based on the analysis of the normalized differential water index (NDWI) proposed by McPheeters, the wavelength combination that constitutes the index is modified. An improved normalized differential water index MNDWI (Modified NDWI) is proposed, and the index has been tested on remote sensing images containing different types of water bodies, and most of them have obtained better results than NDWI, especially the extraction of water bodies within the range of cities and towns. Experiments have also found that MNDWI can reveal the subtle characteristics of water bodies than NDWI, such as the distribution of suspended sediments in water quality[4].

Considering that most of the study area is the estuary of rivers, the concentration of suspended solids such as sediment is high, and the surrounding area is mostly urban buildings, this experiment uses
MNDWI (improved normalized water difference index). In addition, MNDWI can easily distinguish between shadows and water bodies, which solves the difficulty of removing shadows in the water extraction problem. The accuracy of water body information extracted in shallow sea areas with high suspended solids concentration is high. The formula is as follows.

\[
\text{MNDWI} = \frac{\rho_G - \rho_{SWIR}}{\rho_G + \rho_{SWIR}}
\]

In the above formula, \( \rho_G \) is the green band of the image, \( \rho_{SWIR} \) is the short-wave infrared band of the image.

3.2. Region growing algorithm

Region growing algorithm is an image segmentation technology. Its basic idea is relatively simple. It can usually segment the connected regions with the same characteristics and provide useful boundary information and segmentation results. When there is no prior knowledge available, the best performance can be obtained, and it can be used to segment more complex images. Therefore, it shows good performance in processing the south bank of Hangzhou Bay and generating binary images. The basic idea is to combine pixels with similar criteria to form a region based on an absolute discrimination basis. The main step is to find a seed pixel for each region that needs to be segmented as the starting point for growth, and then according to specific criteria, distinguish the similar pixels around the seed pixel, and merge the pixels with higher similarity, just like a seed sprout and grow.

In practice, the key issues are the selection of seeds and the determination of similar regions. First, the selection of seed points requires a specific analysis of specific conditions. In this experiment, pixel points that will be pure in the ocean are selected as seed points. Then, the 8-neighbor or 4-neighbor expansion is performed at the seed point, and an appropriate judgment criterion, namely the threshold \( T \), must be set to divide the binary image effectively.

3.3. Canny operator edge-detection

The edge of the image refers to the part where the local area’s brightness changes significantly. The edge part of the image concentrates most of the information of the image. The determination and extraction of the image edge are very important for recognizing and understanding the entire image scene. It is also an important feature that image segmentation relies edge detection, which is mainly the measurement, detection, and positioning of the gray level changes of the image. Since edge detection was proposed in 1959, after more than 50 years of development, there have been many various edge detection methods. To recognize the edge detection of the image, it is necessary to use the discretized gradient approximation function to find the gray jump position of the gray matrix of the image according to the gradient vector of the two-dimensional gray matrix, and then connect these points in the image to form the so-called edge of the image. The main steps are filtering, enhancement and detection.

The Canny operator edge detection method, which John Canny proposed in 1986, is smoothing first and then obtaining the derivative. There are four main steps in practice: (1) Graying the original image and Gaussian filtering the image (2) Calculating the magnitude and direction of the gradient using the finite-difference of the first-order partial derivative (3) The magnitude of the gradient Perform non-maximum suppression (4) Use dual-threshold algorithm to detect and connect edges.

4. Experimental results and analysis

4.1. Coastline extraction results

For Landsat8 data, the coastline extraction method is specifically: (1) Firstly, it is used the MNDWI to enhance the water body information. (2) Secondly, it is used the region growing method to obtain the
segmentation threshold image. (3) Finally, it is used the Canny operator edge detection to obtain the coastline information.

Because the remote sensing data obtains the instantaneous feature condition at a particular moment, the information about the coastline's dynamic changes can only be determined by multi-temporal remote sensing data. This remote sensing survey uses the satellite remote sensing data of multiple time phases from 2014 to 2019 to obtain the coastline information for many years, and then perform superposition analysis to obtain the coastline information of each period.

4.2. Accuracy evaluation
Accuracy verification is a quantitative evaluation based on a qualitative evaluation, mainly analyzing the degree of agreement between the extracted coastline and the artificially interpreted coastline. This evaluation of accuracy is measured by the average vertical distance between the coastline extracted and the artificially interpreted coastline during the same period. Randomly sample 20 points to measure the vertical distance between the two points, and then perform average processing. The result turns out to be 12.89m. Since the two remote sensing images' resolutions are 30m and 10m, respectively, the error is acceptable within 10-30m. In conclusion, the coastline extracted by this method can be used for correlation analysis of coastline changes.

4.3. Coastline changes analysis
The multi-temporal coastline spatial data extracted by the above method could be analyzed from two aspects: coastline-length change and coastline direction.

From the perspective of coastline length, it can be seen from the Figure 4 that the length of coastline has fluctuated declined since 2014, from 29.66km (2014) to 26.07km (2019).

From the perspective of the coastline's direction, this experiment set the coastline in 2014 as the baseline, and the movement toward the ocean is recorded as positive. Otherwise, it is negative. Simultaneously, two small research areas A and B were selected for the experiment to investigate the movement. The experiment found that the coastlines of the two areas have moved significantly toward the ocean since 2014. Area A has increased from 0.167km (2015) to 0.543km (2019). Area B has increased from 0.065km (2015) to 0.527km (2019).

The coastline of Hangzhou Bay is undergoing dynamic changes from 2014 to 2019. The reasons for coastline changes can be summarized into two aspects: natural factors and human factors. Natural factors mainly include sea-level rise caused by global warming, coastal erosion in areas where rivers enter the sea and areas with high wind and waves, and sediment accumulation in estuaries; human factors mainly include artificial reclamation for urban construction land, coastal aquaculture and other aspects. Among them, artificial reclamation, tidal flat aquaculture, and sea pond construction are the main reasons for
the coastline changes. In addition, the implementation of the Hangzhou Bay Cross-sea Bridge on the south bank of Hangzhou Bay has accelerated the coastline changes in recent years.

![Inter-annual variation of coastline length](image1)

**Fig 3.** Inter-annual variation of coastline length

![Inter-annual variation of forwarding distance of coastlines](image2)

**Fig 4.** Inter-annual variation of forwarding distance of coastlines

5. Conclusion

For Zhejiang, a large coastal province, the coastline plays an indispensable role in ecological construction and economic development. Therefore, the analysis of coastline changes is of great significance to the sustainable use of coastal resources. Therefore, it is important to quickly and accurately extract the southern coastline of Hangzhou Bay.

Compared with traditional surveying methods, the automatic coastline extraction method based on remote sensing images dramatically improves work efficiency and saves costs. This paper summarizes the research progress of automatic coastline extraction methods based on remote sensing images at home and abroad in recent years. It focuses on the method combining the traditional region growing algorithm and the Canny operator edge detection method, which are used to extract the coastline of the Hangzhou Bay from 2014 to 2019. It is used a qualitative study method of the coastline changes, which represents
a fact that the length of coastline has fluctuated declined since 2014. It is concluded that there are two reasonable explanations: (1) sea level rises caused by global warming, coastal erosion in areas where rivers enter the sea and areas with high wind and waves, and sediment accumulation in estuaries. (2) the vigorous economic activities like tidal flat aquaculture and sea pond construction is constructed. (3) the construction of cities and towns such as reclaiming land from the sea is increased.

References
[1] Solomon S M. Spatial and temporal variability of shoreline change in the Beaufort - Mackenzie region, northwest territories[J]. Geo - Marine Letters, 2005, 25(2 - 3):127 - 137.
[2] Zhu J F,Wang G M,Zhang J L,et al. Remote sensing investigation and recent evolution analysis of Pearl River Delta coastline [J]. Remote Sensing for Land and Resources, 2013, 25(3):130 - 137.
[3] Xu H Q. Study on water body information extraction using improved normalized differential water body index (MNDWI) [J]. Journal of Remote Sensing,2005,9(5):589-595.