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Automated Techniques for Quantification of Coastline Change Rates using Landsat Imagery along Caofeidian, China

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Abstract. This paper focuses on automated extraction and monitoring of coastlines by remote sensing techniques using multi-temporal Landsat imagery along Caofeidian, China. Caofeidian, as one of the active economic regions in China, has experienced dramatic change due to enhanced human activities, such as land reclamation. These processes have caused morphological changes of the Caofeidian shoreline. In this study, shoreline extraction and change analysis are researched. An algorithm based on image texture and mathematical morphology is proposed to automate coastline extraction. We tested this approach and found that it's capable of extracting coastlines from TM and ETM+ images with little human modifications. Then, the detected coastline vectors are imported into Arcgis software, and the Digital Shoreline Analysis System (DSAS) is used to calculate the change rate (the end point rate and linear regression rate). The results show that in some parts of the research area, remarkable coastline changes are observed, especially the accretion rate. The abnormal accretion is mostly attributed to the large-scale land reclamation during 2003 and 2004 in Caofeidian. So we can conclude that various construction projects, especially the land reclamation project, have made Caofeidian shorelines change greatly, far above the normal.

1. Introduction

Coastline, the boundary between land and ocean, is a significant symbol of the active and frail coastal zone [1]. Rapid and accurate detection and measurement of coastlines' dynamic change are an important task in both environment monitoring and coastal zone management [2]. Remote sensing techniques, different from the exhaustive and expensive field evaluations [3], have prominent advantages—being macroscopic, comprehensive, high-frequency, dynamic, and low-cost. Therefore, many researchers used remotely sensed data for change detection in coastal environments [4].

Although conventionally, coastlines are manually identified and traced by cartographers using visual interpretation method, automated delineation method has long been desired and researched due to the subjectivity and substantial labor involved in the manual method [5]. Automated coastline extraction algorithms can be mainly divided into three types: edge detection, image segmentation and synthetic method combining different methods together. Edge detection method including Sobel, Roberts [6], Canny [7]and other edge detection operators, is relatively simpler to implement than others. However, the edge pixels detected by the edge detectors are discontinuous and can hardly characterize a coastline completely [5]. Commonly used image segmentation algorithms comprise thresholding [8], classification and so on. They have the advantage in creating continuous boundaries.

In addition, the classification method can make use of different classifiers such as artificial neural network classifier [9], and consider many factors including the texture and spatial correlation, so its accuracy is higher than thresholding and edge detection methods. But the demerits of segmentation algorithms are that they need more post-segmentation processing steps to extract the coastline, and face difficulties in determining a reliable threshold or parameter in the thresholding and classification methods.

Combing the advantages of different methods, synthetic method can not only consider a variety of factors, but also introduce concepts and methods from other disciplines to automate the extraction process. So its inclusiveness is stronger, and application range is wider. Zhuang [10] utilized different methods based on the features of coast including thresholding, edge detection operators, unsupervised classification, supervised classification, morphology operators as well as wavelet transform to extract shorelines in Xiamen, China. Zhang *et al.* [11] proposed a rapid method based on the related information of neighborhood and the theory of two-dimension between-cluster variance for extracting coastlines automatically with high-resolution images form IKONOS. Given the spectral and spatial information, Bagli *et al.* [12] used several morphological segmentation algorithms and evaluated them with ETM+ images. Liu *et al.* [5] presented a comprehensive approach to effectively and accurately extract coastlines form satellite imagery, which consists of a sequence of image processing algorithms including a locally adaptive thresholding technique, Levenberg-Marquardt method and Canny edge detector etc.

Given the different texture features of the land and sea, this work aims to develop an automated extraction algorithm and quantify annual rate of beach changes by remote sensing techniques using multi-temporal Landsat images at the coast of Caofeidian in China.

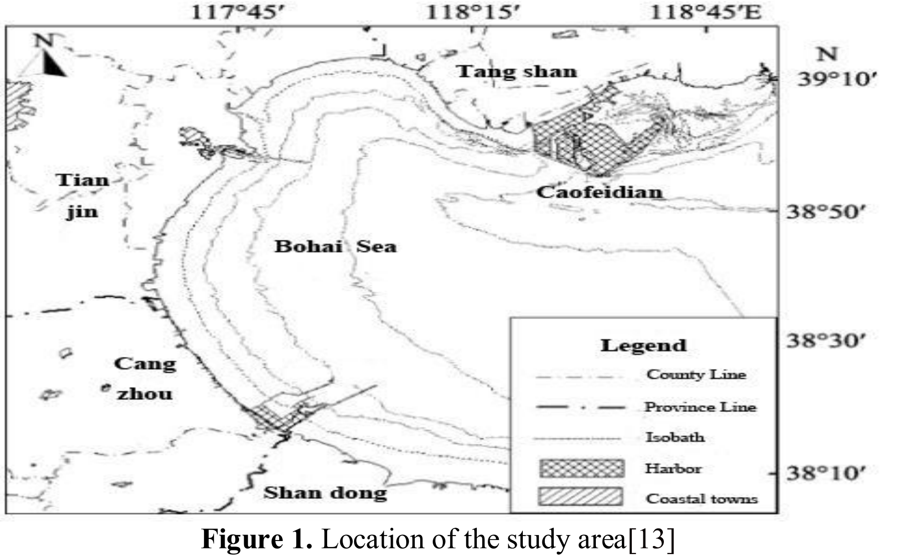


Figure 1. Location of the study area[13]

2. Study area and data sets

Caofeidian, as an important economic region in China, has experienced great changes in the past 15 years due to various construction projects. Considering all factors such as research motivations, cost and study area, Landsat imagery is chosen for study.

2.1. Study area

The study area of Caofeidian coastal zone (Figure 1) is located in the south of Tangshan, Hebei province, between latitude $38^{\circ}54'$ to $39^{\circ}26'$ and longitude $118^{\circ}05'$ to $118^{\circ}50'$. It's adjacent to the Beijing-Tianjin-Hebei metropolitan groups, being an important part of the Bohai economic region. In 2003, Hebei province decided to formally develop Caofeidian with the largest reclamation project ever in China officially launched. At the beginning of 2006, Caofeidian industrial zone construction was included in the national "11th five-year" development program; and at the end of this year, all construction and reclamation projects were completed.

The large-scale sea reclamation project not only promoted the rapid development of the local economy, but also irreversibly changed local environmental conditions. According to official papers, by the end of 2008, vast area of ocean near Caofeidian lost its marine nature, having no natural coastlines. And the data shows that the reclamation area is too large, threatening the sustainable development and worsening the local natural ecological environment.

2.2. Data sets

Satellite images were downloaded from the USGS and CEODE databases, which have been radiometrically and geometrically corrected. According to the quality reports, these products are georeferenced with a level of precision better than 0.5 pixels. We worked with four images (Table 1) corresponding to the 122-033 scene and covering the period from 1995 to 2009.

Table 1. Acquired date, satellite, sensor , resolution and source in this study

Acquired date	Satellite	Sensor	Resolution(m)	Source
1995/11/12	Landsat5	TM	30	USGS
2003/02/11	Landsat7	ETM+	30	USGS
2006/09/23	Landsat5	TM	30	GEODE
2009/04/08	Landsat5	TM	30	USGS

3. Methodology

The overall workflow is mainly divided into three steps: image preprocessing, shoreline extraction and shoreline analysis.

3.1. Image preprocessing

As the downloaded satellite images have been radiometrically and geometrically corrected, the preprocessing procedures only consist of projection conversion, to ensure all the image series have the same projected coordinate systems; image registration examination, to make sure that successive images can overlay perfectly, less than 1 pixel; extracting the images pertaining to the region of interest, i.e. Caofeidian district.

According to the study area introduction, Caofeidian only has man-made coastlines by the end of 2008, which consist of seawall, breakwater, slope protection, dash wall, wharf, tidal gate and road retaining tides. This reinforced concrete structure makes it suffer less effect from tides. Considering the big difference between the culture pond or salt field along the coast with seawater in terms of texture and structure, this research treats water edge as shorelines, ignoring the tide and other effects, thus simplify the extraction process.

3.2. Shoreline extraction

The proposed method is based on the different spectral responses of water and land in the infrared bands, and this method utilizes band 7 to extract coastlines for its good bi-modal nature of the histogram with a darker mode consisting mostly of water pixels [14].

The traditional density slicing method fails to recognize areas where there is culture pond or salt field, which is of sparse structure and contains much seawater. Considering that the texture of land is rich while large areas of waters lacks texture, image texture is quite necessary to enhance the structures of all objects, then morphology operators can be used to get the coastlines. The proposed algorithm based on image texture and mathematical morphology mainly comprises five parts:

- Create texture image, as there are various common texture algorithms, including local statistical measures(contrast, energy, entropy etc.) [15], entropy is chosen;
- Create rough mask for the land, first threshold the texture image, then delete the small objects, smooth the edges, close any open holes, and fill holes in the object with morphology operators(refer to Matlab documentation for more information);

- Use the rough mask to segment the ocean, as Part 2 gets the rough mask for land, then the rough area for water in the original image can be calculated, repeat Part 1 and 2 procedures to the image with only water and the result is the precise ocean mask with islets ;
- Get the precise ocean mask by deleting the lonely islands, i.e. islands with no water in the neighbourhood;
- Trace and vectorize the coastline pixels, various edge detection operators can be used.

The generated coastline vectors from the image series are then imported to geographic information system called Arcgis, final examinations and manual editing can be made to ensure the correctness of the final coastline vectors.

3.3. Shoreline analysis

In this study, Digital Shoreline Analysis System (DSAS) is used to calculate the shoreline change rates. And shoreline changes are estimated using two different kinds of statistical approaches: distance—Shoreline Change Envelope (SCE) and Net Shoreline Movement (NSM), and rate—the End Point Rate (EPR) and Linear Regression (LRR). SCE is the distance between the shoreline farthest from and closest to the baseline at each transect. NSM reports the distance between the oldest and youngest shorelines for each transect. EPR is calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline. LRR can be determined by fitting a least-squares regression line to all shoreline points for a particular transect with the result that the sum of the squared residuals is minimized [16].

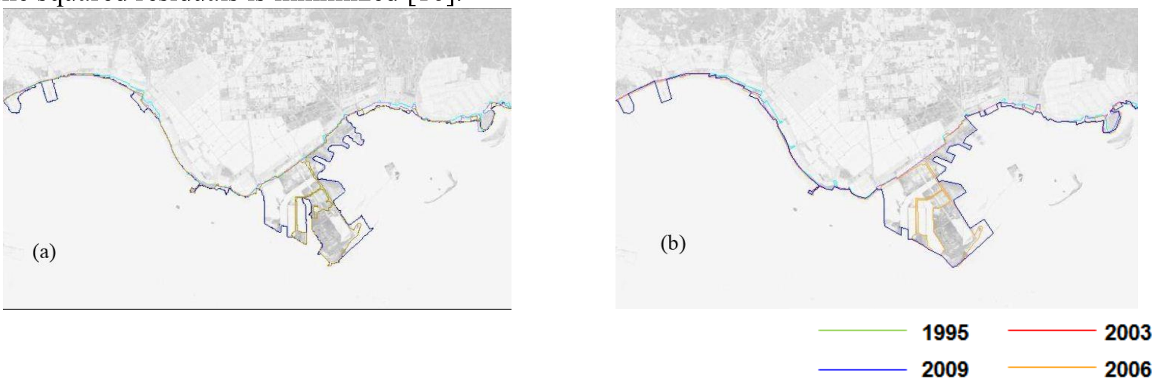


Figure 2. The extracted shorelines from 1995 to 2009, (a) the automatically extracted shorelines, (b) the manually extracted shorelines

4. Results and discussion

In this research, coastlines were extracted from satellite images in 1995, 2003, 2006, and 2009 by using the algorithm based on image texture and mathematical morphology. The shoreline changes were analysed using DSAS software and four statistical parameters: SCE, NSM, EPR and LRR. Using DSAS, transects were spaced 400 m apart, with more than 200 transects in total. Rates of shoreline change were calculated at each transect to all shorelines.

The automatically extracted shorelines are overlaid and shown in Figure 2. It shows that in the period 2003-2009, the biggest changes happened in Caofeidian coastlines. In order to validate the result, manually extracted coastlines are shown in comparison. Obviously, it exhibits little difference between the two in positions, while the manual ones have fewer nodes. So the automatically extracted coastlines require greater capability of data storage.

Table 2 and Figure 3 show that before the year 2003 when the reclamation project didn't start, the coast length tended to decrease as a result of the erosion. After 2003, especially 2003-2006, when the coast zone was under construction, the length increased by more than 20% every year. And in the period from 2006 to 2009, as the main construction part had been completed, the coastline growth rate slowed down, but the increasing trend kept on due to the serious sediment deposition. The satellite images can also show the serious sediment deposition and pollution in the Caofeidian Coast, which affect the quality of the automatically extracted coastlines. Some researches indicated that the highway connecting the inland and the island causes great sediment deposition, the coastline length in Caofeidian will continue to grow if nothing is done to improve the situation.

Table 2. Coastline length change from 1995 to 2009

Date	Length change compared with 1995 (m)	Length change rate compared with 1995(%year)
1995、11	-	-
2003、2	-2444.4	-0.23
2006、9	92561.8	23.7
2009、4	5193.4	2.33

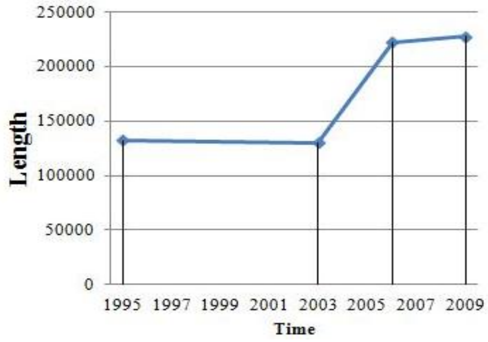
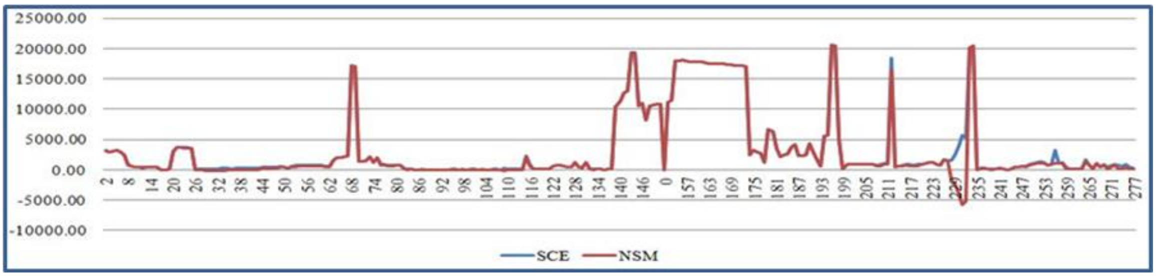
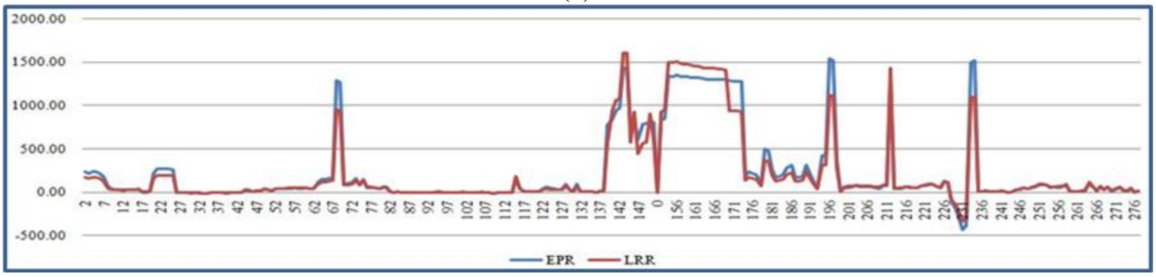


Figure 3. Coastline length



(a)



(b)

Figure 4. Coastline changes in terms of distances in (a), and annual rates in (b) calculated with DSAS from the imagery data. Four statistical parameters are SCE (Shoreline Change Envelope), NSM (Net Shoreline Movement), EPR (End Point Rate), and LRR (Linear Regression).

The coastline changes calculated from Landsat series using the four different statistical parameters in DSAS reveal a good correspondence between them (Figure 4). It can be seen that coastline change rate varies dramatically along the coast, and in the construction area, the increasing rate can reach more than 1000 m/year. Undoubtedly, the main reason is the large-scale reclamation project in a short time. However, not all areas behave like this, change rate in some region is negative, which reveals that this region suffers from erosion. Based on the statistics above, it can therefore be concluded that various construction projects, especially the land reclamation project, have made Caofeidian shorelines change greatly, far above the normal.

The results of this work demonstrate that the algorithm based on image texture and mathematical morphology can be effectively and automatically applied to Landsat imagery to delineate and map coastlines. And the generated shoreline vectors can be accurately analyzed using GIS tools. Although our methodology is operational and effective, some further enhancements should be made in future work. For example, the correctness of extracted coastlines is affected by imagery quality, but the degree of the effects is not researched. The algorithm is only pixel-based, and the tide effect is overlooked. In addition, the automatically extracted shorelines need more memory space than the manual ones, so the simplification and representation of shorelines deserve further study.

Acknowledgments

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