Spatial-temporal Variability of Coastline in Bohai Rim Based on Fractal Dimension

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Abstract

This paper extracted the spatial distribution of the continental coastline of Bohai Rim utilizing Remote Sensing and GIS spatial analysis techniques, and calculated the fractal dimension of the coastline by box-counting method, with a time from 1990 to 2010. Moreover, we analyzed the characteristics of spatial-temporal variability of the coastline's length and fractal dimension, the relationship between the large scales length change and fractal dimension change. During the research period, the coastline length of the study area increased progressively and the most significant change in coastline length was found in Tianjin Municipality. Especially after 2000, the coastline length entered a period of rapid growth. In addition, the fractal dimension of the overall coastline of the study area was between the fractal dimensions of the regional coastlines and was close to the maximum fractal dimensions of these regional coastlines. The fractal dimension of the coastline in Bohai Rim was increasing during the research period, large scale project such as ports construction, reduced tortuous degree of the coastline.

Keywords: Coastline, Remote sensing, Fractal dimension, Spatial-temporal variability, Bohai Rim.

1. Introduction

The coastline not only marks the sea-land boundary but also contains a wealth of coastal environmental information. Changes in coastlines directly affect the resource of intertidal flats; moreover, these changes will cause variations in a variety of resources and ecological process in coastal zones that will eventually affect the survival and development of coastal residents(Cai et al., 2002; Gao et al., 2013). The coastline becomes one of the most traditional areas of research subject. Following "How long is the coast of Britain?"(Mandelbrot, 1967) published, Mandelbrot made a unique analysis of the nature of the coastline, described the uncertainty of the coastline length, thus proposed the concepts of fractal and fractal dimension. Many scientists conducted a more in-depth scientific research for fractal of coastline and construct two methods for calculating the fractal dimensions of coastlines: the divider method (Mandelbrot, 1982) and the box-counting method (Liebovitch and Toth, 1989).

Currently, there are many researches on the coastline variations. However, most of the extraction methods based on remote sensing image processing obtain instantaneous waterline, rather than the coastline in a real sense of the geography. In addition, most studies only research a small scale of shoreline changes and lack of large scale macro-research on spatial-temporal variation of the coastline. Therefore, the study of coastline changes are of great significance for understanding not only ecological environmental variations in coastal zones but also global changes (Yu et al., 2003; Sabyasachi and Amit, 2009). This paper was intended to analyze the spatial and temporal characteristics of coastline variations of Bohai Rim. The study area encompasses the whole Bohai Economic Rim in China, which has been a new growth pole of China's economic development in recent years and the latest driver following the Pearl River Delta and Yangtze River Delta. This belt has gone through major changes in economy and infrastructures, and growth is occurring in various marine development activities, such as fisheries, ocean shipping, petroleum, natural gas, and sea-salt extraction operations, among other pursuits (Liu and Wu, 2008). The range of coastlines studied starts at Yalu River Estuary in Liaoning Province and ends at the junction of Shandong Province and Jiangsu Province (Figure 1).

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2. Materials and Methodology

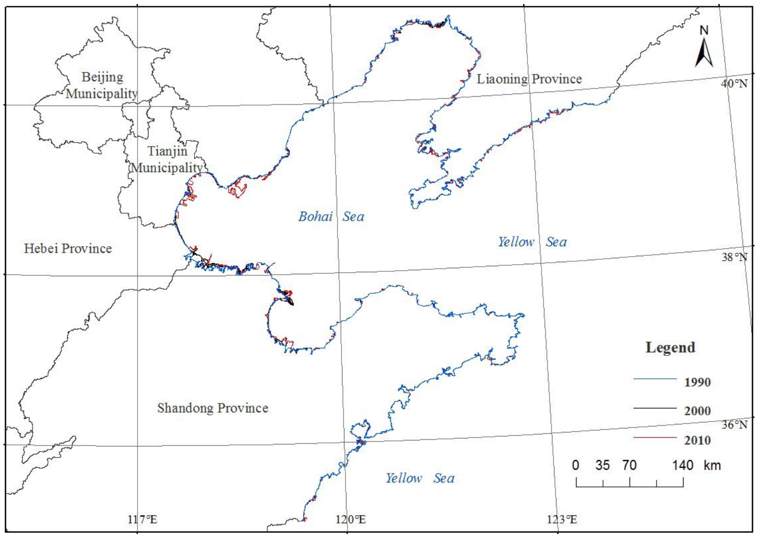


Figure 1. The coastline distribution in Bohai Rim from 1990 to 2010

2.1 Acquisition and processing of the data sources

The remote sensing data sources utilized for the extraction of coastline information included Landsat Thematic Mapper (TM) data and Landsat Enhanced Thematic Mapper(ETM+) data, the spatial resolution of TM data and ETM data are 30 m; Both of these resolutions satisfy the requirements for 1:100,000 mapping. All images were compared with topographic maps for geometric corrections, and the error was never greater than 1 pixel. Auxiliary data used throughout this study primarily include topographic maps, charts and administrative maps of Bohai Rim.

2.2 The method of extracting remote sensing information regarding coastlines

The following principles were used to determine the land-sea boundary for coastal estuaries: retain the harbor-like characteristics of large estuaries; reflect the geomorphologic characteristics of sand spits, shoals, and lagoons of estuaries; manifest the trumpet-shaped morphology of an estuary; treat asymmetric canals based on the shapes of estuaries, assign the dividing line between estuaries to locations where rivers become narrow or the maximum curvature of capes occurs. The land of the tidal flats of the muddy coast (that is not submerged at high tide) was regarded as a collection of islands, and the coastlines of this land were not considered in this study (Zhu et al., 2001). The position of the coastlines in the study area was visually interpreted based on various features on standard false-color remote sensing images, different interpretation standards were applied for the different coast types and specific extraction principle according to documents(Ma et al., 2007; Xu et al.,2013).

2.3 Method of calculating the fractal dimensions of coastlines

This study utilized the box-counting method to calculate these fractal dimensions. The fundamental notion of the box-counting method is used by non-overlapping square grids of different lengths to continuously cover the coastline that must be measured. When the length of the square grid r changes, the number of grids needed to cover the entire coastline, $N(r)$ will shift accordingly. According to fractal theory:

$$N(r) \propto r^{-D} \tag{1}$$

Taking the logarithm on both sides of Equation (1) produces the following relation:

$$\ln N(r) = -D \ln r + C \tag{2}$$

Where C is the constant that must be determined, and D is the fractal dimension of the examined coastline. Using different values of r and $N(r)$, the fractal dimension D can be obtained by fitting analysis. Taken into account that the spatial resolution of the remote sensing data was 30 m, corresponding to the minimum length of a measuring tape measure was 30 m, therefore, the grid size r was selected an integral multiple of 30 m.

3. Results

3.1 Characteristics of the spatial and temporal variation in coastline lengths

Based on remote sensing monitoring, the total length of coastline in Bohai Rim was 6243.22 km. Lengths of this coastline continually increased from 1990 to 2010, and the overall increase during this period of time was 1056.24 km. From 1990 to 2010, the coastline lengths retained the spatial pattern of Shandong Province＞Liaoning Province＞Hebei Province＞Tianjin Municipality. The greatest changes in coastline length occurred in Liaoning Province, where the coastline length increased by 400.47 km, among the examined area.

In order to compare the spatial-temporal differences objectively in the rate of coastline-length change in various periods, the average annual percentage of variation in coastline length during a particular period was used to represent the intensity of the coastline variations (Equation 3, Table 1).

$$LCI_{ij} = \frac{L_j - L_i}{L_i(j-i)} \times 100\% \tag{3}$$

Where LCI_{ij} is the length change intensity of a coastline from year i to year j . L_i is the length of coastline in year i , and L_j is the length of coastline in year j .

Temporally, the coastline length trended of rapid growth after 2000; Regionally, from 1990 to 2010, the most dramatic changes in coastline length were observed in Tianjin Municipality, especially from 2000 to 2010, where the length change intensity of the coastline was 6.84%.

Table 1 The length of coastline of Bohai Rim from 1990 to 2010 (km)

	Tianjin Municipality	Hebei Province	Shandong Province	Liaoning Province	Overall
1990	142.35	438.85	2680.90	1924.87	5186.98
2000	158.28	439.33	2901.10	2011.69	5510.40
2010	266.61	607.94	3043.33	2325.34	6243.22
LCI 1990-2000(%)	1.12	0.01	0.82	0.45	0.62
LCI 2000-2010(%)	6.84	3.84	0.49	1.56	1.33

3.2 Characteristics of the spatial and temporal variation in fractal dimensions of coastlines

To ensure the continuous integrity of the coastline, in the calculation of the fractal dimension of the coastline of Bohai Rim with the box-counting method, the coastlines of Hebei Province and Tianjin Municipality were combined into Beijing-Tianjin-Hebei region(Table 2). From 1990 to 2010, the fractal dimension of the coastline of the entire study area was not equal to the average of the fractal dimension of the individual coastline segments. In addiction, the overall fractal dimension value was close to the maximum of the fractal dimension of the coastline of each individual segment; This result is consistent with the conclusion of previous research regarding the fractal dimension of coastlines(Zhu and Cai, 2004).

From 1990 to 2010, the fractal dimension of the overall coast line of the study area steadily increased, indicating that the geometry of the coastline of the study area became more complex. The fractal dimensions of the coastline in Liaoning Province and Shandong Province tend to variation in accordance with the change in the overall coastline. However, the fractal dimension of Beijing-Tianjin-Hebei region coastline increased rapidly before 2000 then appreciably decreased after 2000.

From 1990 to 2000, among the regions in this study area, the geometries of the coastlines were most complicated in Shandong Province, followed by Beijing-Tianjin-Hebei region and Liaoning Province. In 2010, the fractal dimension of Liaoning coastline became larger than Beijing-Tianjin-Hebei region coastline, and the order of the geometric complexity of the regional coastlines therefore became as following: Shandong Province > Liaoning Province > Beijing-Tianjin-Hebei region.

Table 2 The fractal dimensions of coastline of Bohai Rim from 1990 to 2010

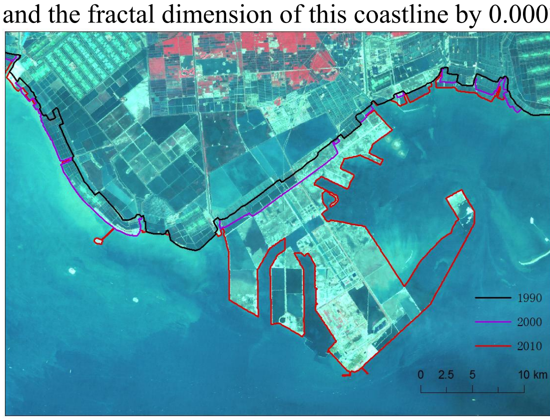
	Beijing-Tianjin-Hebei region	Liaoning Province	Shandong Province	Overall
1990	1.0451	1.0445	1.0528	1.0488
2000	1.0544	1.0528	1.0685	1.0611
2010	1.0531	1.0711	1.0724	1.0691

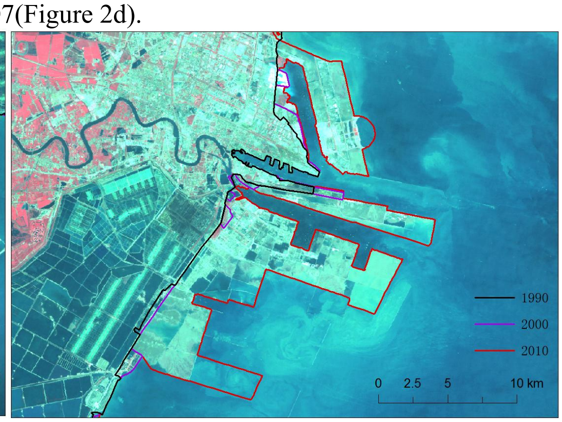
3.3 Analyses of the relationship between large scales length changes and fractal dimension

Changes in the fractal dimensions of coastlines resulted from the combined actions of numerous coastline dynamics variation at various scales. To further analyze the influence of coastline dynamics variation of large scales on fractal dimensions, an experiment was designed where changes in the coastline length and fractal dimension of the overall coastline that resulted from the dynamics of a certain coastline merely were calculated with the assumption that the rest coasts status remained the same.

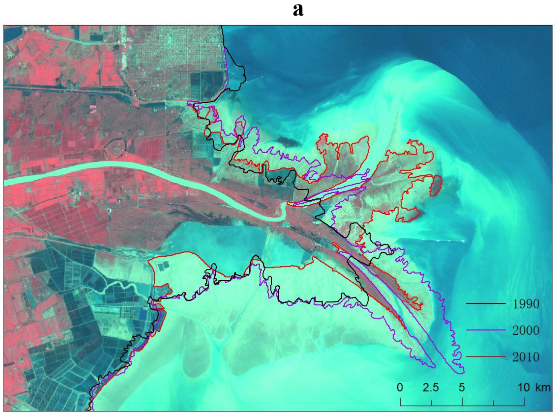
From 2000 to 2010, the construction of Caofeidian Port, which increased reclamation area by 22792.24 ha and the coastline length by 113.57 km. However, which decreased the fractal dimension of this coastline by 0.0008. The construction of Tianjin Harbor Industrial Zone, which increased the coastline length by 46.66 km and decreased the fractal dimension of this coastline by 0.0003. Additionaly, coastline changes caused by erosion and siltation in Bohai Rim were mainly concentrated in Yellow River Delta area and its vicinity. The coastline dynamics of Yellow River mouth area had a significant impact on the fractal dimension of the examined coastline. Sedimentation was very strong in the new mouth of Beicha ditch, which increased silting area by 3432.37 ha and coastline length by 47.32 km, and increased the fractal dimension of this coastline by 0.0002 as well. Whereas erosion was relatively strong at the sand spit of the original Qingshuigou mouth, which shortened coastline length of its north river bank by 41.45 km, reduced fractal dimension of this coastline by 0.0002. (Figures 2a, 2b and 2c).

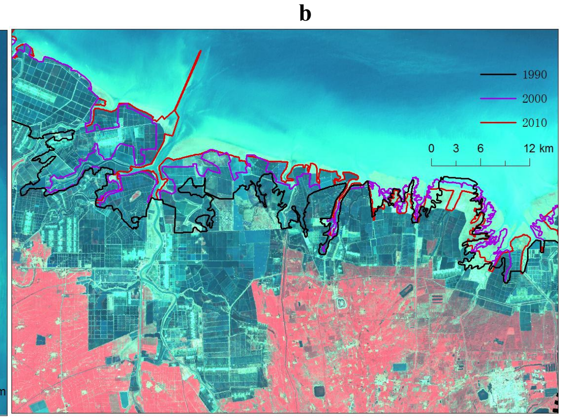
From 1990-2000, a change in one coastline segment in Binzhou, Shandong Province, caused reduction in the fractal dimension significantly of the examined coastline, decreasing the coastline length by 38.24 km and the fractal dimension of this coastline by 0.0007(Figure 2d).





a b





c d

Note: Figure 2a shows the coastline change in Caofeidian Port; Figure 2b shows the coastline change in Tianjin Harbor Industrial Zone; Figure 2c shows the coastline change in Yellow River Delta; Figure 2d shows the local coastline change in Binzhou coastal zone.

Figure 2. Examples of coastline changes in Bohai Rim

4. Conclusions

In this paper, Remote Sensing and GIS techniques were utilize to extracting the spatial and temporal distribution of continental coastlines in Bohai Rim from 1990 to 2010. The box-counting method was utilized to calculate the fractal dimensions of the coastlines in different periods. We analyze the characteristics of spatial and temporal changes in the examined coastlines and the relationship between the large scales length changes and fractal dimension. The major conclusions are as follows:

(1) The lengths of this coastline continually increased from 1990 to 2010. Additionally, the greatest changes in coastline length occurred in Liaoning Province among the examined areas. Temporally, the coastline length entered a period of rapid growth after 2000; Regionally, from 1990 to 2010, the most dramatic changes in coastline length were observed in Tianjin Municipality.

(2) The fractal dimension of the overall coastline of the study area was between the fractal dimensions of the regional coastlines and was close to the maximum fractal dimensions of these regional coastlines. From 1990 to 2010, the fractal dimension of the overall coast line of the study area steadily increased, indicating that the geometry of the coastline of the study area became more complex. Although large scale project such as ports construction, multi in the way of natural shoreline extending outward or horizontal pushing, accelerated the growth of land area, but reduced tortuous degree of the coastline.

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