Differences of Coastline Length and Fractal Dimension Between Pixel-level and Sub-pixel Edge Detection of Coastline Extraction: A Case Study of the Eastern Coast of The Pearl River Estuary

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ABSTRACT: Coastline variations reflect the situation of coastal zones. There are many different methods to extract the coastline from remote sensing images. The Canny edge detector is one of the most popular edge detection methods to obtain coastline from remote sensing datasets. Meanwhile, sub-pixel edge detection could provide more precise edge information compared with the pixel-level edge detection method. In this study, we chose the Pearl River Estuary's eastern area, the most complex coast in China, as the study area. We extracted coastlines from Landsat by Zernike and Canny edge detection. To understand the differences between these two methods, we compared the coastline length and fractal dimension of the study area. The length of the coastline extracted by the pixel-level is 108.28 km, while the length of the coastline obtained by the sub-pixel level is 114.11km. From the Fractal Dimension, we found that coastline extracted by sub-pixel edge detection (FD=1.130) is greater than that extracted by pixel-level edge detection (FD=1.118). Our results show that the sub-pixel edge detection method can extract longer and greater results of coast length and complexity than routine pixel-level edge detection method, suggesting more precise results of costal line length and complexities from sub-pixel methods.

1. Introduction

As the boundary between land and sea (Liu et al., 2013; Ghosh et al., 2015), coastline reflects the situation of coastal zones (Ghosh et al., 2015). A large number of scientists focused on monitoring coastline variations which could help understand the situation of the coastal area and protect its environments (Ghosh et al., 2015; Dai et al., 2019). Remote sensing image is widely used to extract coastline because it can provide higher frequency analysis compared with fieldwork in the past decades (Ford 2013; Sagar et al., 2017). Meanwhile, different coastline extraction methods could provide different precision results (Song et al., 2017).

In the past few decades, a large number of researches focused on pixel-level coastline extraction.

For instance, Chen, W., et al. extracted coastline of the Waisanding Sandbar from 1993 to 2008 by using Canny edge detection (Chen et al., 2009). It is well known that pixel-level extraction could provide edge information for scientists. However, the accuracy of pixel-level edge detection cannot meet the requirements of edges in some cases. Sub-pixel edge detection has been proposed to solve this problem (Hermosilla et al., 2008)

In this study, we selected the eastern part of the Pearl River Estuary as the study site. We applied Canny edge detection and Zernike moments edge detection to extract coastlines from Landsat 8 OLI_TIRS in 2018. Then, we compared coastline length and Fractal Dimension calculated from coastline extraction. Finally, an analysis of pixel and sub-pixel level is discussed extensively.

2. Methodology

2.1 Study Area

In this study, we selected the eastern part of the Pearl River Estuary (PRE) as the study area (22° 30' -22° 45'N, 113° 43' -114° 2'E). This area enjoys mild weather and high precipitation (Zhao et al., 2014; Wu et al.,2016). The tidal condition of the study area is weak (Xu et al., 2019), and the tidal influence is less than one pixel (Hu and Wang., 2020).

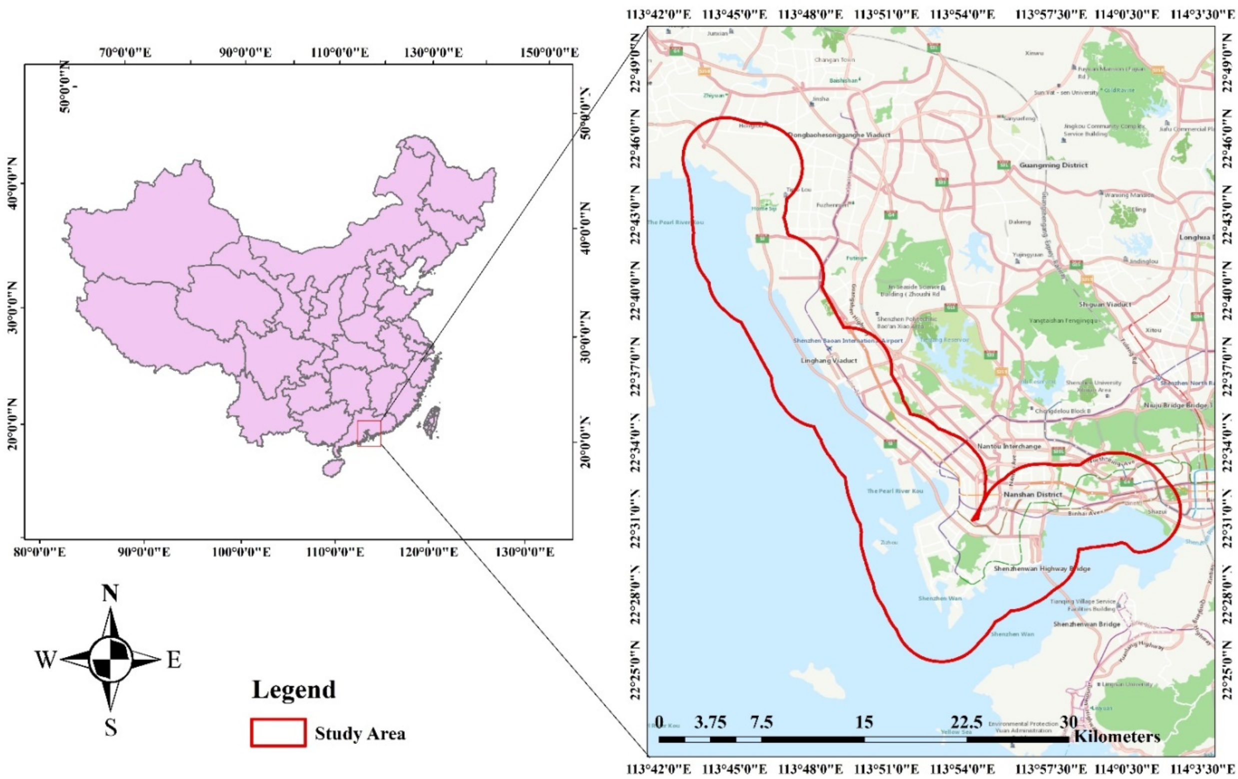

Figure 1. Study Area of this paper showing the eastern part of the Pearl River Estuary (PRE)

2.2 Data Collection

In this study, we downloaded Landsat 8 OLI_TIRS dataset via Geospatial Data Cloud (http://www.gscloud.cn/). The detail information of the remote sensing image is shown below in Table 1. Here, we selected a clear image on February 12, 2018, with nearly no cloud (cloud cover less than 10%) and no occlusion of the coastal zone.

Table 1. Involved dataset of this study

Date (yy/mm/dd)	**Start time**	**Spatial Resolution (meter)**	**Land Cloud Cover (%)**	**Scene Cloud Cover (%)**	**WRS Path**	**WRS Row**
2018/2/12	02:51:40	30	8.31	7.55	122	44

2.3 Processes of Extraction and Analysis

In this study, we used ENVI 5.1, ArcGIS 10.3 and MATLAB 2017a to extract coastline and calculate the Fractal Dimension. The processing flow is shown in Figure 2.

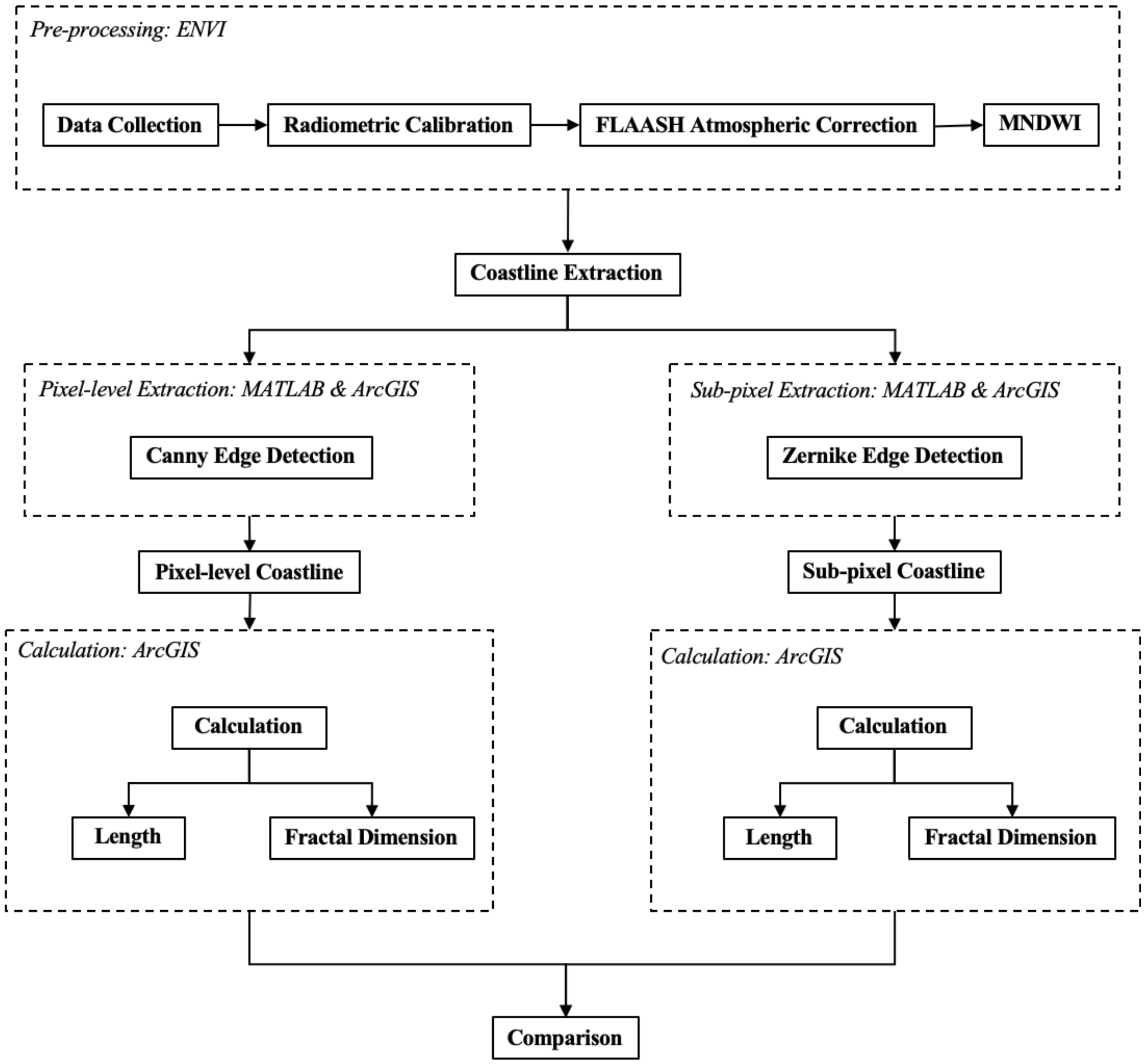

Figure 2. The flow chart of this study

In this study, ENVI 5.1 was involved in finishing pre-processing, including Radiometric

Calibration, FLAASH Atmospheric Correction and Modified Normalized Difference Water Index (MNDWI).

After these steps, MATLAB 2017a was used to extract coastline by using both pixel-level and sub-pixel algorithm. In this study, we selected Canny edge detection as the pixel-level coastline extraction algorithm and Zernike edge detection as the sub-pixel one.

Canny edge detection is one of the most popular detectors which could provide a more precise comparison with other pixel-level detectors (Chen et al., 2019). Ghosal et al. firstly proposed Zernike moments in 1993 (Ghosal and Mehrotra, 1993) which could provide edge information with only three masks and saved 33% run time compared with Lyvers' approach (Qu et al., 2005).

We calculated coastline length and Fractal Dimension of both coastlines in ArcGIS 10.3. For calculation of the Fractal Dimension, we used the box-counting method, which first came up with Gagnepain and Roques-Carmes in 1986 (Gagnepain and Roques-Carmes, 1986). This method uses squares with different side lengths to cover the objects and counts the number of squares. When the size of squares changes, the number of squares changes as well (Eq. 1). The FD was calculated by equation 1, where N represents the number of squares, and r represents the size of the squares. Considered the spatial resolution of involved remote sensing imagery (Hu and Wang, 2020), we used squares with 210 m, 300 m, 1200 m, 2700 m, and 6000 m in this study.

$$FD = -\lim_{r \to 0} \frac{\log N(r)}{\log r} \quad \text{Eq. 1}$$

3. Results

3.1 Length

Figure 3 (a) and (b) show the coastlines extracted by pixel and sub-pixel edge detection methods, respectively. From the result, the length of the coastline extracted by the pixel-level is 108.28km, and it is 114.11km for that extracted by sub-pixel level. For the same area, sub-pixel edge detection provided longer coastline in this study.

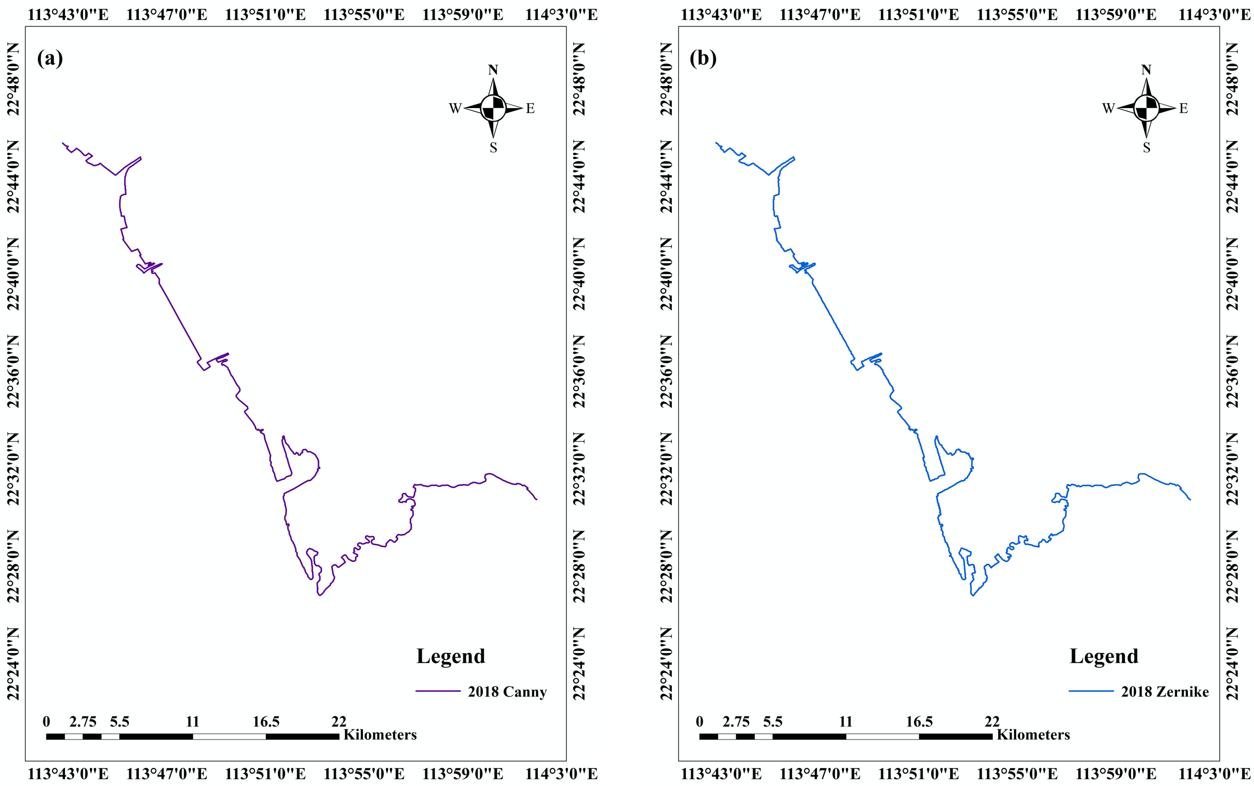

Figure 3. Coastline Extraction by different methods (a) Pixel-level edge detection (b) Sub-pixel edge detection of the study area

3.2 Fractal Dimension

From coastline length, we know that pixel-level and sub-pixel edge detection obtain different lengths. FD of these two coastlines described different coastal complexity based on coastline length. For pixel-level edge detection coastline, the FD is 1.118, while it is 1.130 for sub-pixel edge detection coastline. Based on this value, sub-pixel coastline shown more complexity than the pixel-level coastline.

Table 2. The length and FD of coastline extracted by different methods

	Length (km)	**Fractal Dimension**
Pixel-level	108.28	1.118
Sub-pixel	114.11	1.130

4. DISCUSSION

The results indicate that the coastline extracted by sub-pixel method obtained a longer length than the pixel-level edge detection method. Compared with coastlines extracted by pixel-level method, more details of coastline could be detected by sup-pixel edge detection method. Based on this point, the complexity of coastline extracted by sub-pixel edge detection would increase due to it is more irregularity than the pixel-level coastline. This viewpoint was verified by the Fractal Dimension result in this study that the sub-pixel method received 1.130, and pixel-level received 1.118. Combined the result of coastline length and Fractal Dimension, it could be found that the

sub-pixel method could provide more detailed information about the coastline. Besides, previous studies also pointed out the similar results that sub-pixel edge detection could provide more precise edge information compared with pixel-level one (Qu et al., 2005).
Besides, the Fractal Dimension value of these two methods reflected that different extraction method would receive different complexity result of coastlines. In this study, it could be found that the sub-pixel method receives enormous Fractal Dimension value which indicated that sub-pixel coastline is more complicated than the pixel-level coastline. The edge extracted by pixel-level is not adequate to provide a precise edge (Sun et al. 2016). On the contrary, the location and orientation of the edge detected by the sub-pixel level method are within one pixel (Agustin et al. 2013; Hermosilla et al. 2008). Thus, edge detected by the sub-pixel level is closer to the real edge and more precise than pixel-level provided (Zhang 2019). From this point, edge provided by sub-pixel level is more fluctuated, which reflected by the enormous value of the Fractal Dimension.
In this study, we selected the eastern part of the PRE as the study area, the time and space span could be more extensive in the further study to describe more comprehensive analysis between these two methods. For coastline variations monitoring studies, it is significant to choose a reasonable method which can provide more accurate results. Meanwhile, some methods indeed could provide more precise result but need to solve the difficulties of a large amount of calculation. For instance, Zernike moments operator could provide more precise result compared with pixel-level edge detector, but it required a longer run time (Qu et al., 2005). Thus, some scientists proposed to combine the pixel-level and sub-pixel edge detector to provide precise edge detection with a short run time (Qu et al., 2005; Yang, 2015).

5. CONCLUSION

This study applied pixel-level and sub-pixel edge detection to extract coastline of the eastern part of the PRE from Landsat 8 OLI_TIRS. Based on the coastlines extracted in this study, we calculated and compared the coastline length and Fractal Dimension by these two methods. The results indicated that the sub-pixel edge detection method provides longer length and more complexity coastal condition, which could provide more details of edge information than pixel-level method. For future analysis, we can monitor coastline variations of the PRE in the past few decades by using pixel-level and sub-pixel edge detection to understand the differences between these two methods whether in more extensive time and space span.

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