

# Comparison of Coastline Extraction Methods and Block Classification Method to Extract Coastlines based on Remote Sensing

Zongmei Li (✉ [lizongmei106@163.com](mailto:lizongmei106@163.com))

Xiamen University of Technology

Hongmei Chen

Xiamen University of Technology

Qin Nie

Xiamen University of Technology

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## Research Article

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# Comparison of coastline extraction methods and block classification

## method to extract coastlines based on remote sensing

Zongmei Li\*, Hongmei Chen, Qin Nie

*Department of Spatial Information Science and Engineering, Xiamen University of Technology, Xiamen 361024, China;*

\*corresponding author E-Mail: [lizongmei106@163.com](mailto:lizongmei106@163.com)

### ABSTRACT

Coastlines change with urbanization, and methods to extract coastlines have been previously reported. However, comparisons of these methods are rare. Based on remote sensing image, methods of coastline extraction, namely, the visual interpretation method, the threshold segmentation method, improved normalized water indexes and edge detection algorithms and were studied in Xiamen City, China. The best method to extract coastlines was then determined. The results show that the visual interpretation method for coastline extraction was inefficient. The threshold segmentation method was suitable for small-scale, but not large-scale, coastline extraction, based on coastline area. Improved normalized water indexes were insensitive to sediment shadows. The Sobel method (edge detection algorithms) was suitable for large-scale coastline extraction but could yield false edges. Finally, the block classification method, which combines the advantages of different extraction methods, specifically the threshold segmentation method and improved normalized water indexes, was studied. The results of this study show that coastline extraction by the block classification method is easier and produces better results than coastline extraction by other methods. Therefore, block classification is recommended for the study of coastlines and coastal ecology in large areas.

### Introduction

Due to urbanization and global climate change, the areas of cities and towns have changed<sup>1,2</sup>. In addition, pressures from land changes, human impacts and sea level rise have increased, constituting a serious threat to the stability of coastal ecosystems<sup>3-5</sup>. To cope with these problems, it is crucially important to monitor dynamic coastline changes, which are meaningful to ecosystem management and protection<sup>6</sup>. Coastline information is essential to understand coastal ecosystem changes. Thus, it is necessary to study methods of coastline extraction.

At a large scale, it is challenging and costly to extract coastline information concerning the extent of the coastal zone. Remote sensing is a well-established coastline extraction technique. When using remote sensing images, there are many methods for coastline extraction, such as the visual interpretation method<sup>7</sup>, the threshold segmentation method<sup>8</sup>, modified normalized water indexes<sup>9</sup>, and edge detection algorithms<sup>10</sup>. Remote sensing images, including optical remote sensing data<sup>7</sup>, multispectral remote sensing data<sup>11</sup> and microwave remote sensing data<sup>12</sup>, are used for coastline extraction. Optical remote sensing data include high resolution and medium resolution data. High resolution remote sensing data are expensive, and some are classified. In contrast, medium resolution remote sensing data such as moderate resolution Landsat image are almost always free.

Based on medium resolution remote sensing data, a large number of coastline extraction efforts have been conducted. Using pan sharpening approaches, Liu et al.<sup>13</sup> improved the accuracy of coastline extraction from Landsat-8 OLI images, and Wang et al.<sup>14</sup> researched spatiotemporal changes using Landsat images (MASS, TM, ETM and OLI). Coastlines have also been extracted

from the normalized difference water index (NDWI) and the modified normalized difference water index (MNDWI)<sup>14</sup>. Shoreline position can be deduced from Landsat imagery using the methods described in Pardo-Pascual et al.<sup>15</sup> and Almonacid-Caballer et al.<sup>16</sup> Coastline extraction methods are divided into three types, namely, the visual interpretation method, semiautomatic interpretation method and automatic interpretation method. The visual interpretation method requires large amounts of time and labor. The most common methods for coastline extraction are semiautomatic interpretation methods. Coastline extraction by the automatic interpretation method almost always needs post-processing. The semiautomatic interpretation method is divided into the threshold segmentation method, which features gray bands, and water splitting methods such as MNDWI and boundary detection, which are also called edge detection algorithms. Because there are so many available methods for coastline extraction, it is important to develop a novel method that both performs well and is efficient.

This research aims to find the optimal method for coastline extraction. We compare coastline extraction via the visual interpretation method, the threshold segmentation method, the MNDWI method, and edge detection algorithms and show the advantages and disadvantages of these different methods. Additionally, we combine different methods to produce a novel method for coastline extraction, which is meaningful for the study of coastal ecological environments and for coastal ecological restoration.

## Results

### Coastline extraction using different methods.

#### *Threshold segmentation method*

As shown in the image of Fig. 1, the gray values of the ground features were studied in the study area (Fig. 1). We found that the gray values of water and other ground features had greater differences in the fifth band. We chose the fifth band to process the threshold segmentation. Water and land were separated. After image enhancement, the results became clear; the details of these results are shown in Fig.2. The threshold segmentation method was easily used to extract the coastline. However, we found that some water, farm, and vegetation areas had similar gray values and overlapped (Fig. 2). The length of the coastline was 218.074 km (Tab.1). Fractal dimension of coastline extracted by different methods is little different.

#### *Modified normalized water indexes (MNDWI)*

Using normalized water indexes (NDWI) and MNDWI, the coastline was extracted. In a comparison of NDWI and MNDWI, we found that the MNDWI of construction were negative and smaller than the construction NDWI, and the MNDWI of water were positive and larger than the water NDWI (Fig. 3a and 3b). The different ground features of the MNDWI had greater differences than those of the NDWI. These differences benefit binarization processing (Fig. 3c). Taking Dadeng Island as an example, the MNDWI are insensitive to sediment shadow (Fig. 3b), which is beneficial to coastline extraction. Using MNDWI, the coastline of Xiamen was extracted (Fig. 3d). The resulting coastline length was 223.419 km.

#### *Edge detection algorithms*

Based on neighborhood averaging, Sobel model detection smooths noise; therefore, the results of this model are less affected by noise. There are two problems with this technique: first, a bigger neighborhood means less noise but harsher edges. Second, there may be false edges (Fig. 4a and 4b). Coastline extraction with Sobel model detection is beneficial for the extraction of large areas<sup>7</sup>.

The length of the coastline was 221.63 km, and the fractal dimension was 1.0247.

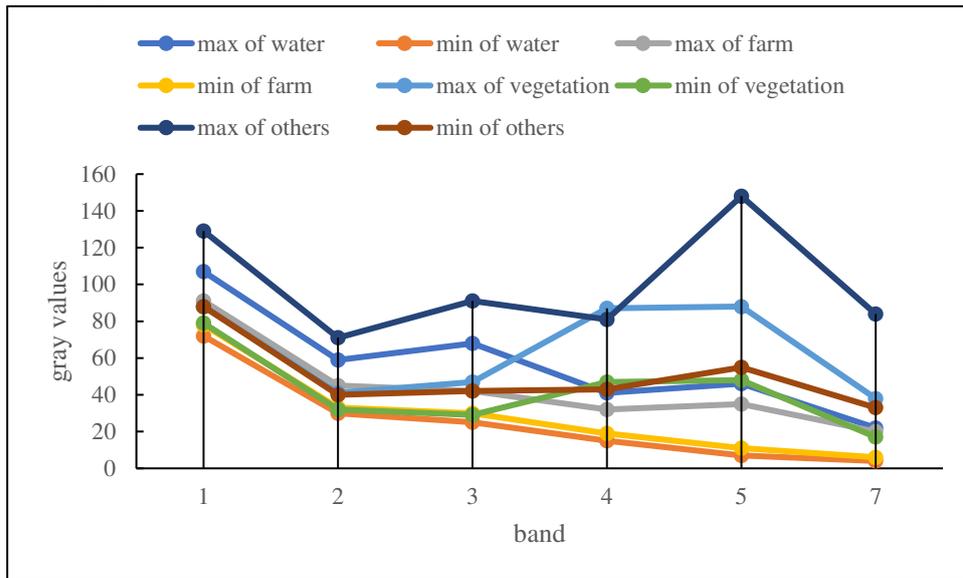


Fig. 1 Gray values of different features in different bands

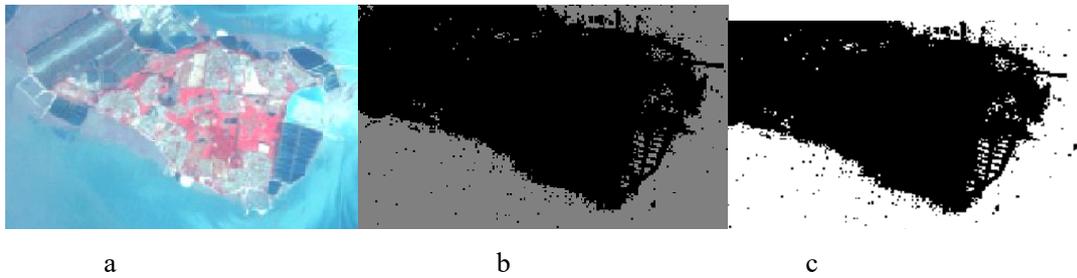
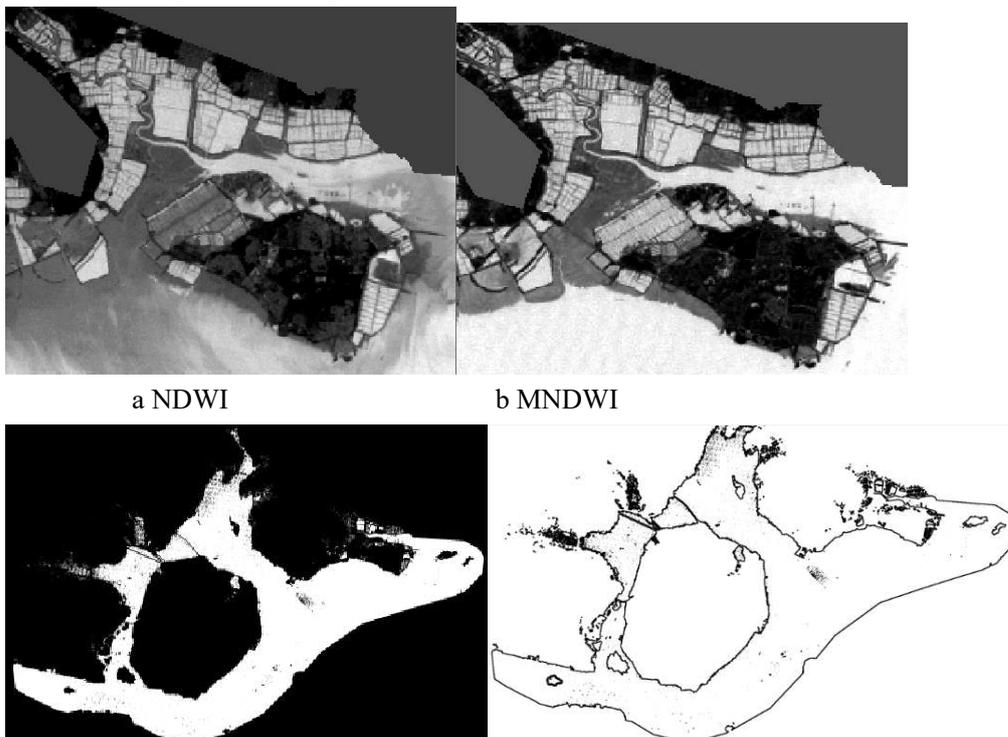


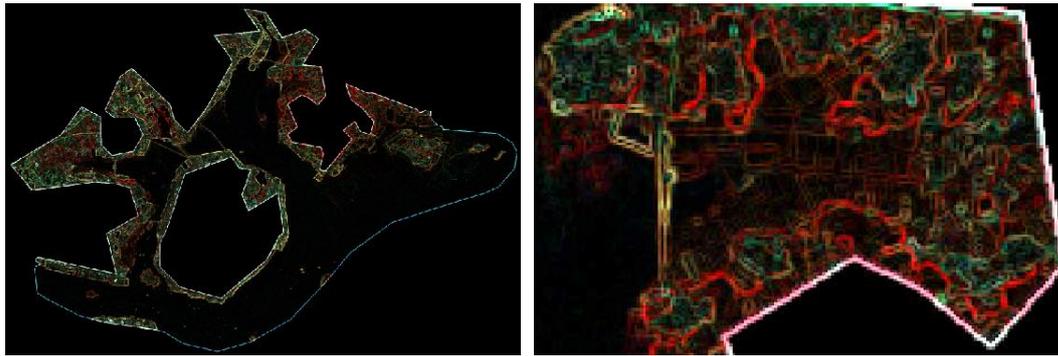
Fig. 2 Parts of water, farm, and vegetation areas with similar or overlapping gray values. Image a is a remote sensing image (432 band). Image b is Image a after threshold segmentation. Image c is Image b after image enhancement.



c binarization processing

d boundary extraction

Fig. 3 Coastline extraction by MNDWI.



a the whole coastline

b detailed part of the coastline

Fig. 4 Coastline extraction via the Sobel edge detection method.

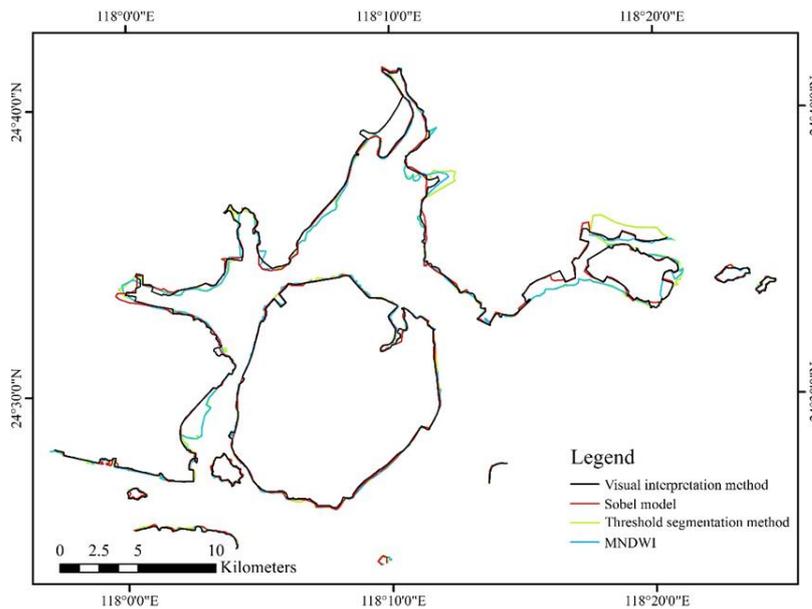


Fig.5 Coastline extraction by different methods.

### Comparisons of coastlines extracted by different methods

#### *Comparisons of coastlines extracted by different methods in Xiamen City*

The coastlines extracted via different methods had different spatial distributions (Fig. 5). Coastline extraction by the visual interpretation method was used for validation data because this method has been shown to be accurate. The spatial distributions of different coastlines extracted via different methods demonstrated similar trends, but some areas differed. According to the coastline extracted via the visual interpretation method, the coastline extracted by the MNDWI method had a lower absolute error and relative length error than those extracted by the Sobel model (Tab. 1). In addition, the fractal dimension of the coastline extracted by the MNDWI was the nearest to that extracted by the visual interpretation method. The complexity of the extracted coastlines decreased in the order of the MNDWI, visual interpretation method, threshold segmentation method, and Sobel model coastlines.

Fig. 5 shows the spatial distribution of extracted coastlines; the red line and the black line have greater superposed areas than the other lines (Fig. 5). As a result, the Sobel model coastline has the most accurate spatial distribution, which is showed in Table 1. For coastline extracted by Sobel

model, the absolute error of length and Relative error of length is most small.

In Dadeng island, coastlines from different models presented different spatial distributions. The coastline extracted by the Sobel model was similar to that extracted by the visual interpretation method (Fig. 6). The MNDWI and threshold segmentation methods had weak performances distinguishing silt and construction.

Tab. 1 Lengths and fractal dimensions of coastlines extracted by different methods

Methods	Length (km)	Fractal dimension	Absolute error of length (km)	Relative error of length (%)
Visual interpretation method	232.343	1.0358		
Threshold segmentation method	218.074	1.0258	14.269	6.14
Modified normalized water indexes (MNDWI)	223.419	1.036	8.924	3.84
Sobel model	221.63	1.0247	10.713	4.61

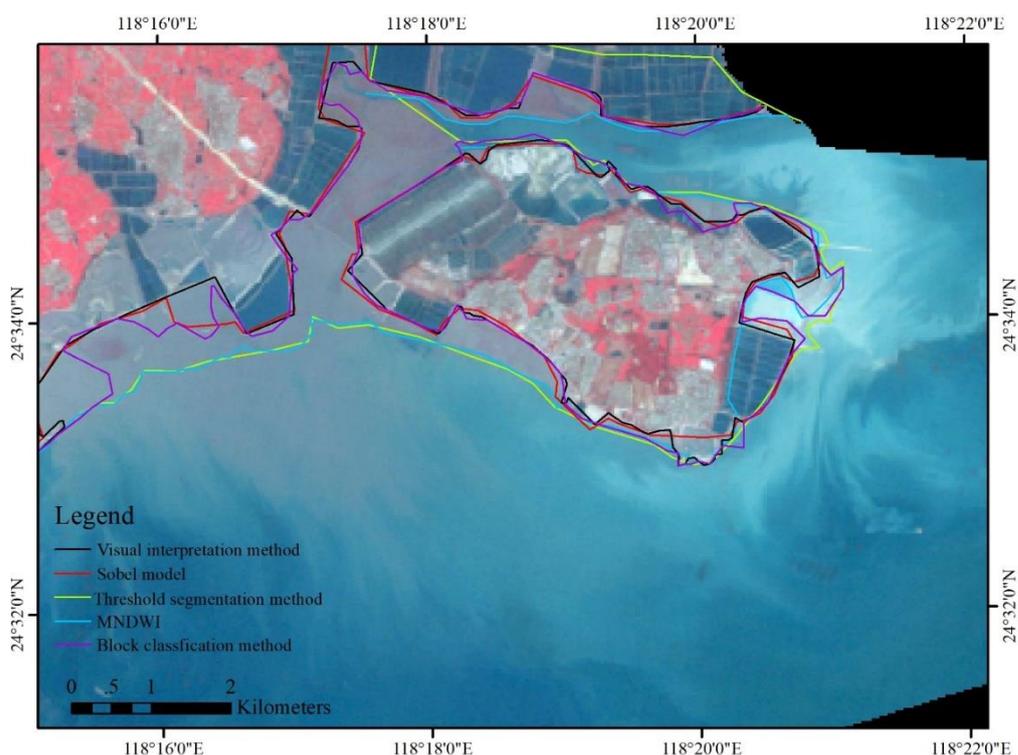


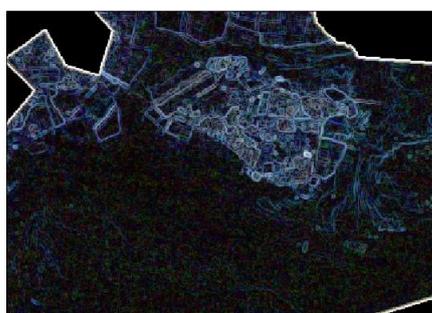
Fig. 6 Coastlines extracted via different methods superimposed over the remote sensing image (false color) of Dadeng Island

### Coastline extraction by the block classification method in Dadeng Island

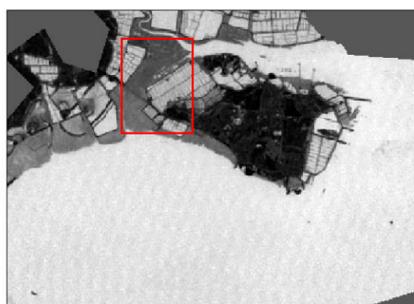
the Sobel model was the best model for coastline extraction for Dadeng island. However, the coastline needed a large amount of post-processing because of false edges (Fig. 7a). Compared to coastline extraction using the Sobel model, coastline extraction with the MNDWI method requires a small amount of post-processing (Fig. 7b). The application of treatment is needed to eliminate silt

errors. The block classification method was used for coastline extraction. The block size used in this paper is 5km\*10km, size of Fig. 6, and the MNDWI were calculated in this area (Fig. 7b). The threshold segmentation method was used in the MNDWI image. We found the silt area was extracted when the MNDWI were greater than -0.1 but less than 0.2, and the water area was extracted when the MNDWI were greater than 0.55. Silt and water areas were binary as 0, and the other areas were 1 (Fig. 7d). The silt area was easy to extract (red square in Fig. 7).

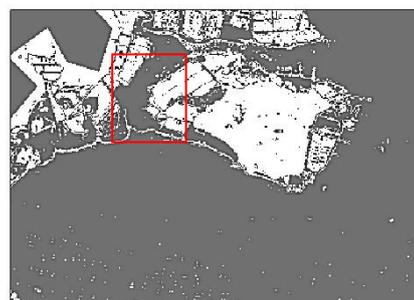
The coastline extracted by the block classification method with MNDWI had a similar spatial distribution and trends as that extracted by the visual interpretation method (Fig.6). In contrast with the use of MNDWI to extract the coastline of Xiamen, after MNDWI were calculated in the block area and threshold segmentation method, the influence of silt was eliminated. Thus, the block classification method and different methods combined were the best coastline extraction methods in this paper.



a Sobel model



b MNDWI



c Binarization processing of MNDWI. d Threshold segmentation method of MNDWI.

Fig. 7 Coastline extraction by the block classification method (combining the MNDWI and threshold segmentation methods).

## Discussion

Coastline detection and extraction using remote sensing data have extensive applications, and different methods and data can be used to extract coastlines. Choosing the best method of coastline extraction using free image data is important for research. In this research, we use Landsat TM images to determine the best method to extract coastlines.

The threshold segmentation method can be easily used to extract coastlines. The threshold for coastline extraction is determined by analyzing the gray values of surface features in different bands. However, some gray values of water, farm, and vegetation areas can be similar and overlap. Using Landsat TM images, coastline can be extracted by the threshold segmentation method<sup>8</sup>. Different image bands are associated with different spectrum information. The gray values of different bands

have correlating properties, so some may overlap<sup>17</sup>.

MNDWI are easily used to extract construction and water areas and is insensitive to sediment shadows<sup>18</sup>. Based on MNDWI, coastlines have been extracted in China and other areas such as Jiangsu province (coast of the Yellow River)<sup>19</sup>, Zhejiang province<sup>14</sup>, and Fujian province<sup>7,20</sup> in China; Hatiya Island in Bangladesh<sup>21</sup>; and Rosetta promontory in the Nile Delta<sup>22</sup>.

Edge detection algorithms, taking the Sobel model as an example, are the most accurate of the four studied methods for coastline extraction. However, edge detection algorithms may produce false edges, and this drawback means a high amount of post-processing is required. The Sobel model has been used to extract coastlines in some areas. For example, coastlines were extracted by the Sobel edge detection model with NDVI and NDWI in Dubai<sup>23</sup>. Shoreline extraction with the Sobel method proved to be efficient for Shichiri Mihama in Japan<sup>24</sup>. In China, the Sobel model has been used to extract coastlines in Caofeidian in Hebei province<sup>25</sup>.

Due to disadvantage and advantage of different coastline extraction method, block classification method to detect coastlines was studied. The MNDWI method is easy to calculate<sup>18</sup>. However, sediment shadows affect the coastline accuracy of MNDWI. We divided Xiamen into blocks because the threshold segmentation method for coastline extraction is more accurate in smaller study areas. The optimal block size varies over different study areas. In this paper, we chose a block size with 5km\*10km, which is larger than the area of Dadeng Island. eliminating sediment shadow was key; the threshold segmentation method was used to eliminate the sediment shadow, which may also be useful for the extraction of silt areas. The above method for coastline extraction, called the block classification method, was accurate and easy. After an image is divided into blocks, the effect of the noise on the threshold is reduced<sup>26</sup>. Relationship between threshold segmentation method accuracy and scale size was studied<sup>27</sup>. In large scale, segmentation results were interactive with other information. Accuracy is increased as scale decreased This idea is applied to MNDWI to increase the accuracy of coastline extraction. Block classification method makes it easier and higher accuracy to extract coastline.

## Conclusions

This paper presents and compares the extractions of a coastline from a Landsat TM image via different methods. The advantages and disadvantages of the different methods are reported. Size of block is 5km\* 10km, which is greater than area of Dadeng Island. we combined the advantages of MNDWI and the threshold segmentation method and split the image into blocks; this method was named the block classification method. Coastline extraction was easier and more accurate with the block classification method than with other methods. In addition, block classification removed the effect of silt from the image.

## Materials and methods

### Study area

The coastal zone of Xiamen city was selected as the study area (Fig. 8). As a relatively small city, Xiamen has an area of approximately 1699.39 km<sup>2</sup>. By the end of 2019, Xiamen had a registered population of 4.29 million, which is a large population for this area. Xiamen consists of six districts: Siming, Huli, Jimei, Haicang, Xiangan and Tongan.

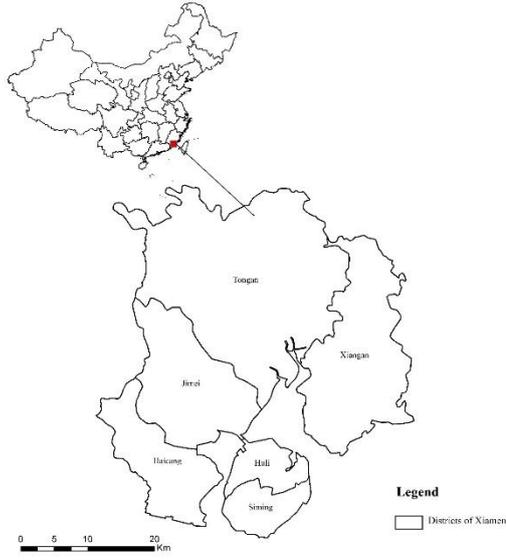


Fig. 8 Districts of Xiamen City, located in China.

## Data

A cloud-free TM image acquired in 2011 served as the primary data for mapping the coast line in the study area. The image was projected onto a 1:10,000 topographic map of Xiamen.

## Methods

Five methods were used to extract the coastline from the TM image. The coastlines extracted via the five methods were compared and analyzed to determine the best method.

### *Visual interpretation method*

The visual interpretation method, which is the basic coastline extraction method, was used to extract the coastline by an experienced professional. The method extracts the coastline after TM image enhancement. The results of this method, compared to those of other methods, are currently the most accurate but require high amounts of time and energy.

### *Threshold segmentation method*

The threshold segmentation method was used to extract the coastline based on gray values of the TM image. First, the gray values of different surface features were studied in different bands in the study area. Second, the bands were compared to distinguish different ground features. The model can be expressed as<sup>28</sup>:

$$I_{ij} = \begin{cases} 255, & I_{ij} \geq T \\ 0, & I_{ij} < T \end{cases} \quad (1)$$

where  $I_{ij}$  is the gray value of any pixel, and  $T$  is the threshold.

### *Modified normalized water indexes (MNDWI)*

MNDWI were devised according to normalized water indexes and can be expressed as follows<sup>29</sup>:

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR} \quad (2)$$

where  $NDWI$  is the normalized water indexes,  $GREEN$  is the green band, and  $NIR$  is the near-infrared band.  $GREEN$  and  $NIR$  are the first and fourth bands, respectively, of the Landsat 5 TM image.

MNDWI are modified in band calculation, which can be expressed as follows<sup>18</sup>:

$$MNDWI = \frac{GREEN - MIR}{GREEN + MIR} \quad (3)$$

where  $MNDWI$  is the modified normalized water indexes,  $GREEN$  is the green band, and  $MIR$  is the middle-infrared band. The MDNWI method has some advantages; for example, in DNWI, gray values in the water and construction areas are positive numbers with a relatively low mean difference and more noise. However, in MDNWI, the construction gray values are negative numbers, which benefits the elimination of construction. Visible radiation is abundant information in MDNWI, which can detect more water information than DNMI.

### *Edge detection algorithms*

Based on gray values, edge detection algorithms inspect the gray value changes in neighborhoods via the first derivation. In this paper, the Sobel model is chosen for coastline extraction. The Sobel edge detection algorithm formula is defined as<sup>30</sup>:

$$s(i,j) \triangleq |\Delta_x f| + |\Delta_y f| \quad (4)$$

where  $s(i,j)$  is the value of the Sobel edge detection algorithms,  $\Delta_x f$  is the horizontal convolution operator, and  $\Delta_y f$  is the vertical convolution operator. According to the neighboring gray values to the right and left as well as above and below, the formula of  $\Delta_x f$  and  $\Delta_y f$  is:

$$\Delta_x f: \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}, \quad \Delta_y f: \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \quad (5)$$

### *Block classification method*

When the study area is large, searching for the thresholds of different surface features requires difficult techniques. For the block classification method, the study area is divided into a few areas. The optimal area will be study in different study area, for example 1km\*1km, 5km\*5km, 10km\*10km and so on. In different blocks, different thresholds are determined easily. In this paper, after the block area is confirmed, MNDWI are calculated, and then the threshold segmentation method is used with MNDWI. That means the coastline is extracted by a combination of different methods.

### *Fractal dimension*

Fractal dimension is used to represent complexity. There are two methods used to calculate fractal dimension, i.e., the gauge method and the grid method. In this paper, the grid method is used to calculate fractal dimension. The basic idea of this approach is that for different sides of nonoverlapping squares that continuously cover the whole coastline, when the sides are changed, the grid numbers required to cover the coastline differ. The formula is<sup>31</sup>:

$$N_k(\varepsilon_k) \propto \varepsilon_k^{-D} \quad (6)$$

$$\lg N_k(\varepsilon_k) = -D \lg \varepsilon_k + A \quad (7)$$

where  $D$  is the fractal dimension,  $N$  is the grid number required to cover coastline,  $\varepsilon$  is a side of the square,  $k$  is the different number of grids that cover the coastline, with  $k$  values of 1,2,3.....n, and  $A$  is constant.

## **Acknowledgments**

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## Author contributions

Zongmei Li is corresponding author, with conceived the ideas and write the paper. Hongmei Chen analyzed data and designed methodology. Qin Nie checked the paper. All authors contributed critically to the drafts and gave final approval for publication.

## Competing interests

The author(s) declare no competing interests.

## Data availability

Landsat data is used during this study are available on

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# Figures

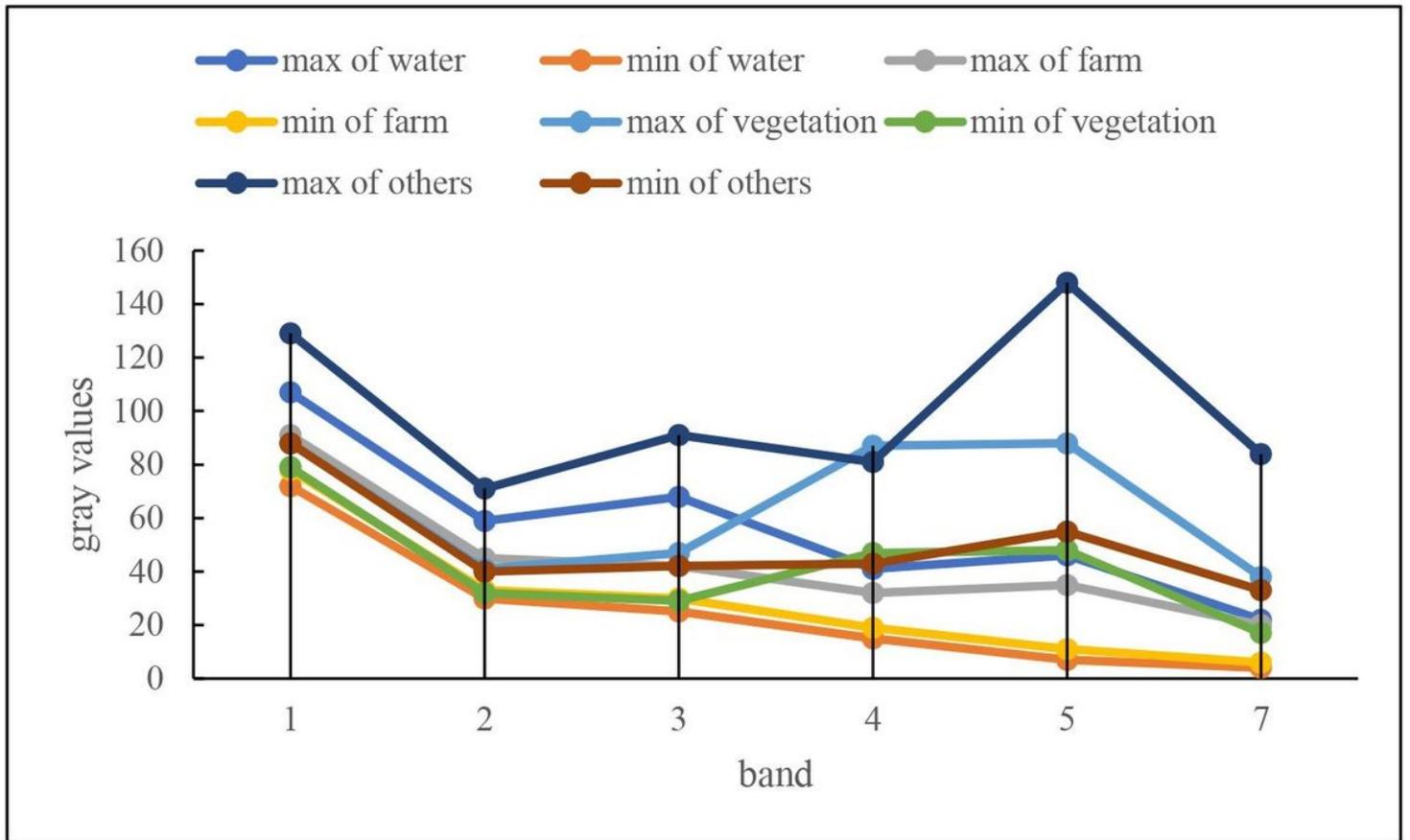


Figure 1

Gray values of different features in different bands

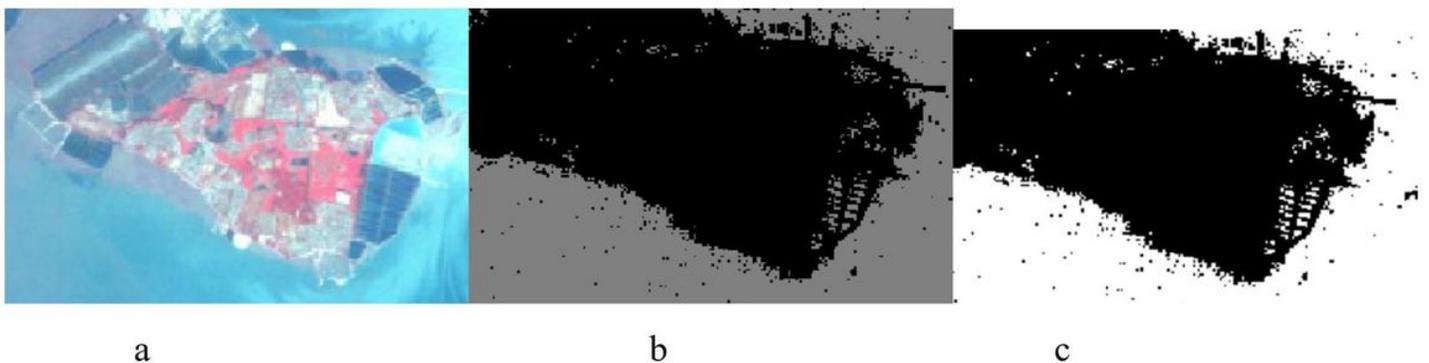
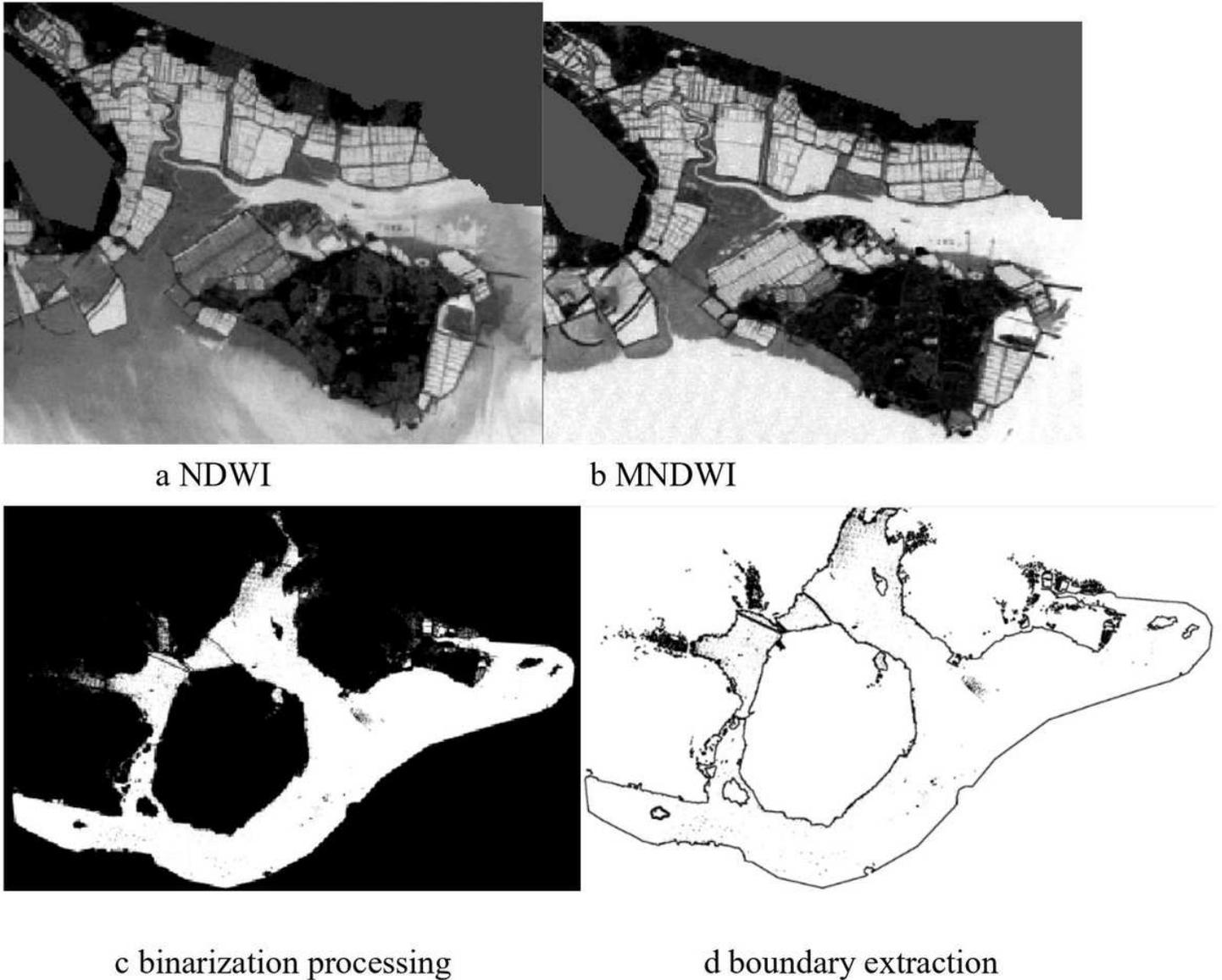


Figure 2

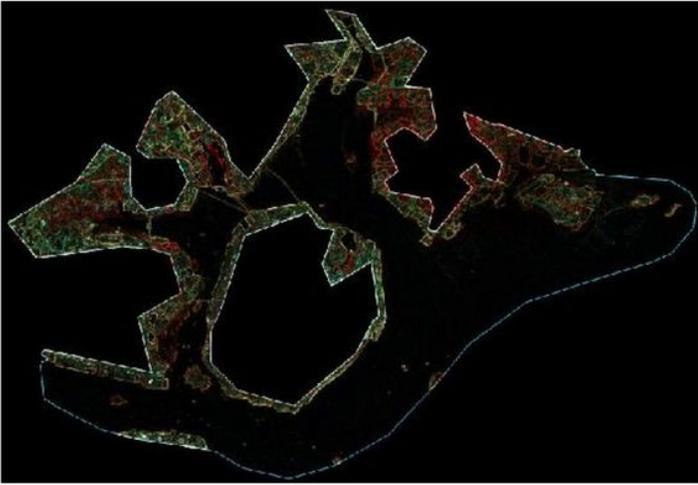
Parts of water, farm, and vegetation areas with similar or overlapping gray values. Image a is a remote sensing image (432 band). Image b is Image a after threshold segmentation. Image c is Image b after image enhancement. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the

legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

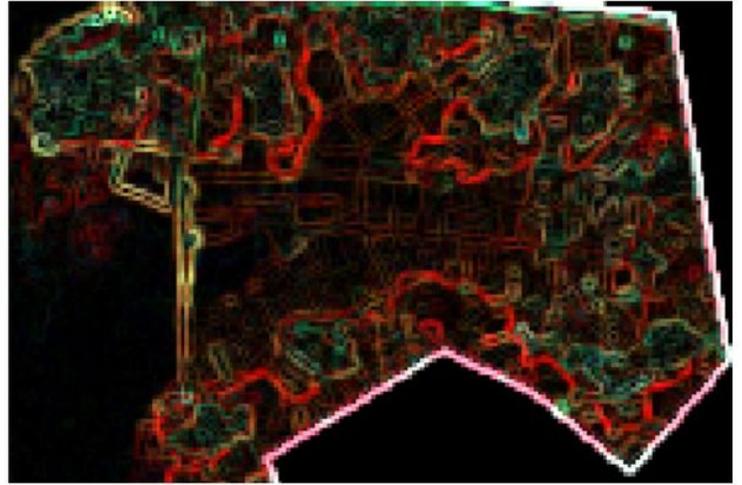


**Figure 3**

Coastline extraction by MNDWI. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



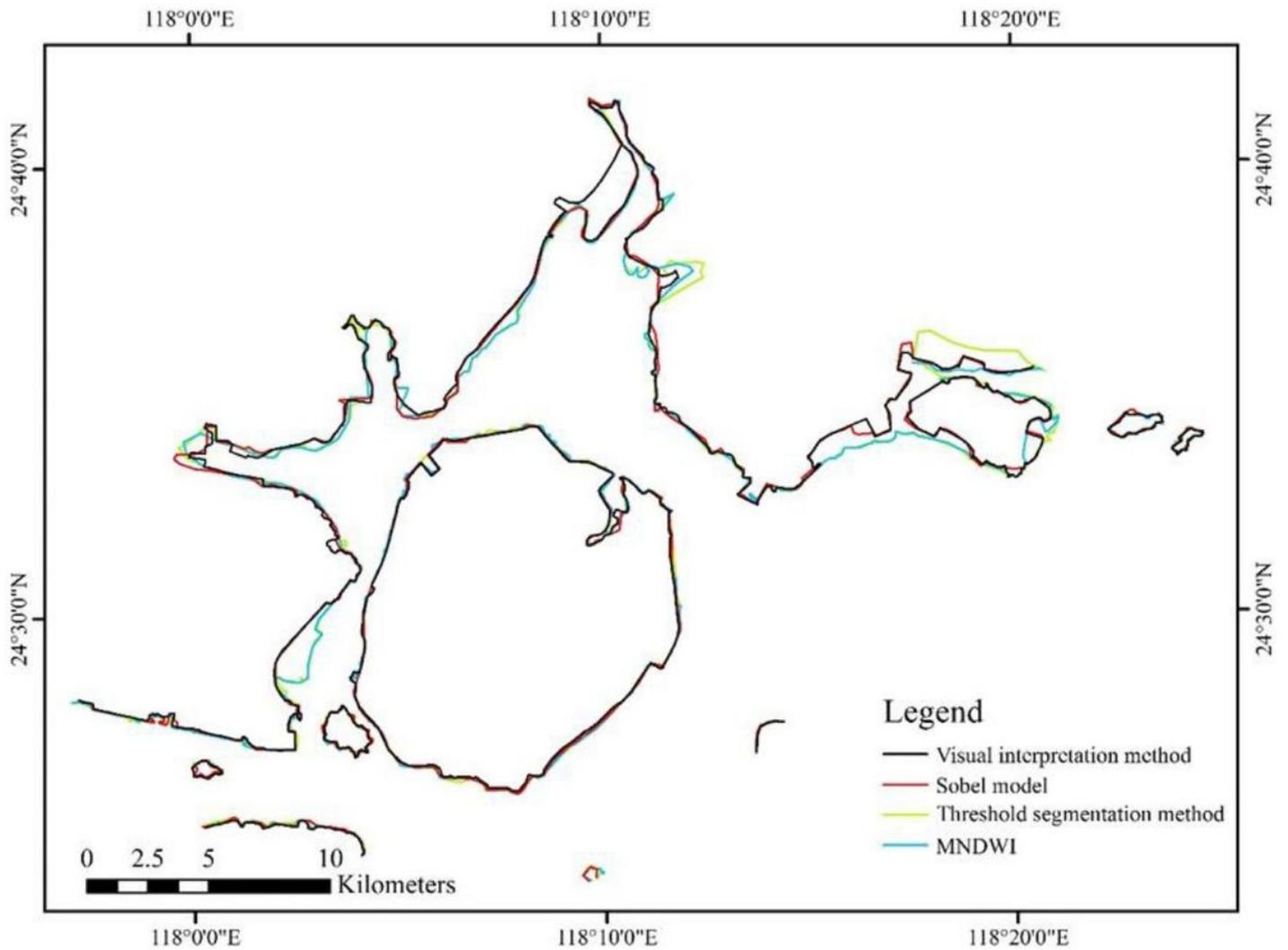
a the whole coastline



b detailed part of the coastline

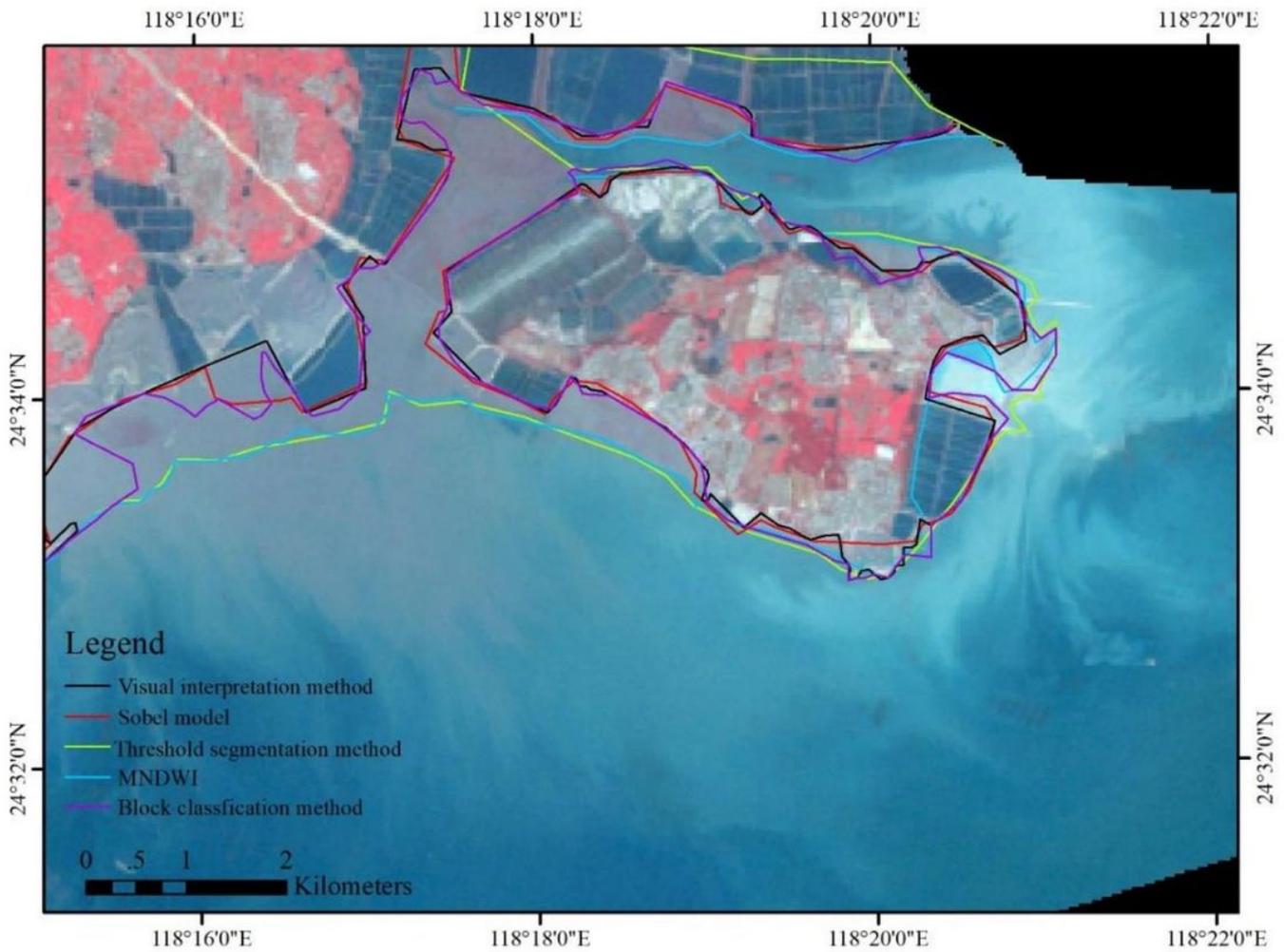
**Figure 4**

Coastline extraction via the Sobel edge detection method. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



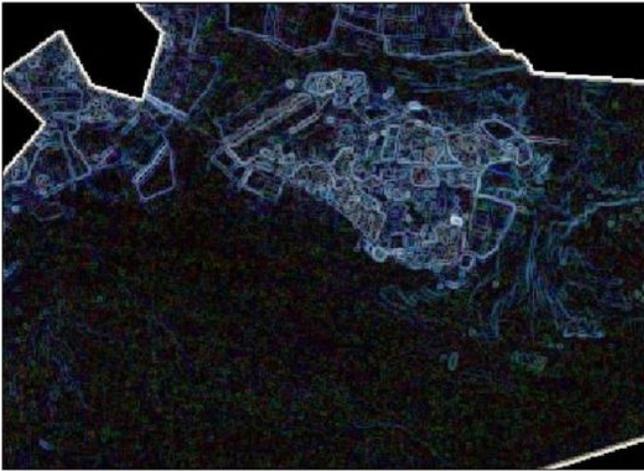
**Figure 5**

Coastline extraction by different methods. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



**Figure 6**

Coastlines extracted via different methods superimposed over the remote sensing image (false color) of Dadeng Island Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



a Sobel model



b MNDWI



c Binarization processing of MNDWI.



d Threshold segmentation method of MNDWI.

### Figure 7

Coastline extraction by the block classification method (combining the MNDWI and threshold segmentation methods). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



**Figure 8**

Districts of Xiamen City, located in China. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.