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Chapter 12

Analysis of Urban Impervious Surface in Coastal Cities: A Case Study in Lianyungang, China

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Additional information is available at the end of the chapter

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Abstract

Impervious surface is an important indicator of the level of urbanization. It is of great significance to study the impervious surface to promote the sustainable development of the city. In the process of urban development, the increase of impervious surface cities is bound to be accompanied by a reduction of one or more types of land use in the city. This paper, taking Lianyungang as an example, introduces the methods of extracting urban impervious surface based on VIS model, NDVI (normalized vegetation index), MNDWI (modified normalized water body index), and unsupervised classification, analyzes the changes of impervious surface in Lianyungang from 1987 to 2014, and on this basis, analyzes the trend and driving forces of land use types in Lianyungang city in depth. The results show that the impervious surface of Lianyungang increased by a total of 29.70% between 1987 and 2014. While the impervious surface continues to increase, the area of cultivated land and coastal areas (including salt works and tidal flats) has been greatly reduced, and the types of land use have undergone significant changes.

Keywords: impervious surface, urbanization, land use, driving factor

1. Introduction

Impervious surface refers to the natural or artificial surface that can prevent vertical runoff (surface water penetrates directly into the soil), mainly including asphalt pavement, square and roof of buildings [1]. As a typical component of surface coverage, the impervious surface can be used as a basis for measuring the difference of urbanization level in different areas,

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and it is one of the important indexes to measure the urban ecological environment [2]. It is of great importance to study the impervious surface of the city in terms of more effective solutions to urban problems and the promotion of sustainable urban development.

Remote sensing is the most important and effective technology of monitoring impervious surface. The methods of remote sensing for monitoring impervious surfaces are usually classified into three types [3, 4]: interpretation and classification, model simulation and spectral analysis method, which mainly includes CART [5–7], Multiple Regression [5], Image Classification [5], Sub Pixel Classification [1, 8], and ANN [6].

As one of the first open coastal cities in China, Lianyungang has now developed into an international port city and one of China's top 10 seaports. Lianyungang is still the East Bridgehead of the New Eurasian Continental Bridge, the East Bridgehead of the Silk Road Economic Belt, the pilot city of the national innovation, and the central city for the development of the coastal areas of Jiangsu. In addition, Lianyungang is an important population concentration area and a center for political, economic, and cultural activities. It has obvious locational advantages and valuable resources, and it has great advancement and leading role in the development of the national economy. Studying the dynamic changes of impervious surface in Lianyungang city can help us understand the development history of Lianyungang city and promote the sustainable development of the city and the scientific development of the economy. Although the definition of impervious surface in cities has attracted widespread attention among relevant scholars and researchers, there are few research data on the impervious surface of coastal cities represented by Lianyungang city. Since the reform and opening up, the rapid development of Lianyungang has caused a lot of urban problems. Based on the theoretical model of V-I-S, this study uses the NDVI index, MNDWI index, and unsupervised classification technology to extract and analyze the impervious surface of Lianyungang city.

2. Study area and data used

2.1. Study area

Lianyungang city is located on the eastern coast of mainland China and is located in the northeast of Jiangsu province (**Figure 1**). The geographical range is between latitude 33°59′–35°07′N and longitude 118°24′–119°48′E. The total land area is 7499.9 km^2, the water area is 1759.4 km^2, and the urban built-up area is 120 km^2. Since the reform and opening up, the level of urbanization in Lianyungang city has been developing rapidly. Its most obvious manifestation is the continuous increase in impervious surface. With the development of globalization and information technology, the urbanization process of Lianyungang city will continue to deepen.

2.2. Data used

The data used in this study were downloaded from the USGS. A total of four images were recorded in 1987, 1996, 2005, and 2014. All images are from the US Land Exploration Satellite System. The auxiliary data are the administrative boundary vector data of Lianyungang city. Specific image data information is shown in **Table 1**.

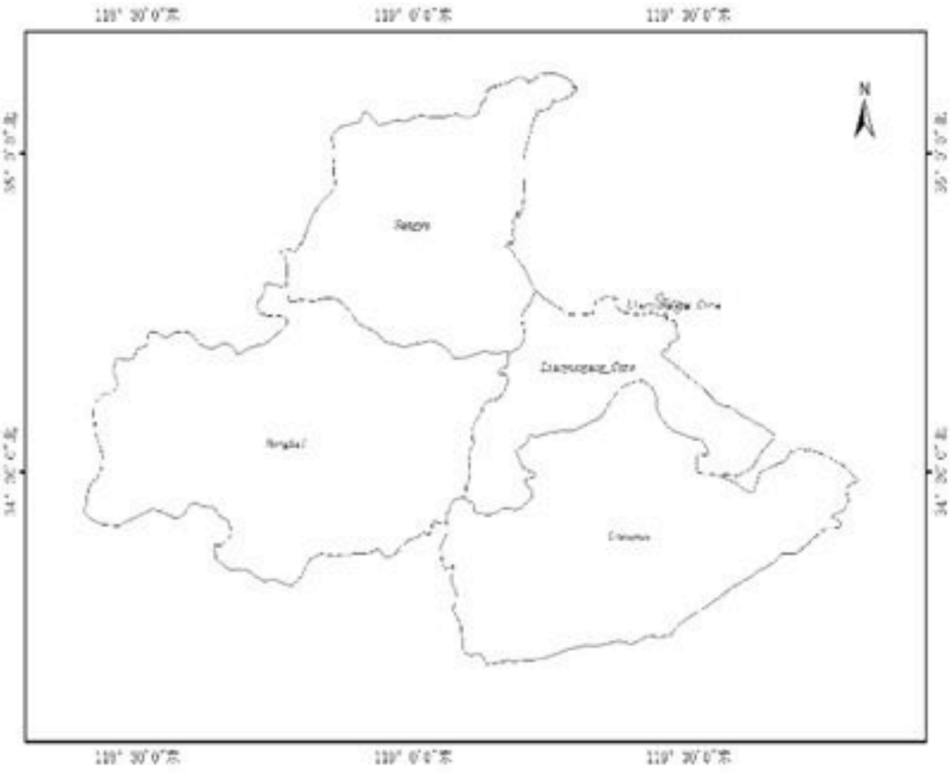


Figure 1. Study area.

Years	1987		1996		2005		2014	
Sensor type	**Landsat 5 TM**		**Landsat 5 TM**		**Landsat 5 TM**		**Landsat 8 OLI**	
Date	21.Sep	11.Aug	13.Sep	20.Sep	24.Oct	31.Oct	1.Oct	24.Oct
Path	120	121	120	121	120	121	120	121
Row	36	36	36	36	36	36	36	36
Cloud cover	0.26	6.89	8	0	1	1	0.08	20.93

Table 1. Remote sensing image data information of Lianyungang.

3. Method

The main technical route of this study is shown in **Figure 2**.

3.1. Data preprocessing

Due to the limited geographical location of the remote sensing image, Lianyungang city is made up of two adjacent remote sensing images. In order to ensure that the different sensors or the same sensor from different days of the image can be compared, and to eliminate the radiation caused by atmospheric radiation error [9], radiation calibration and atmospheric correction should be carried out first.

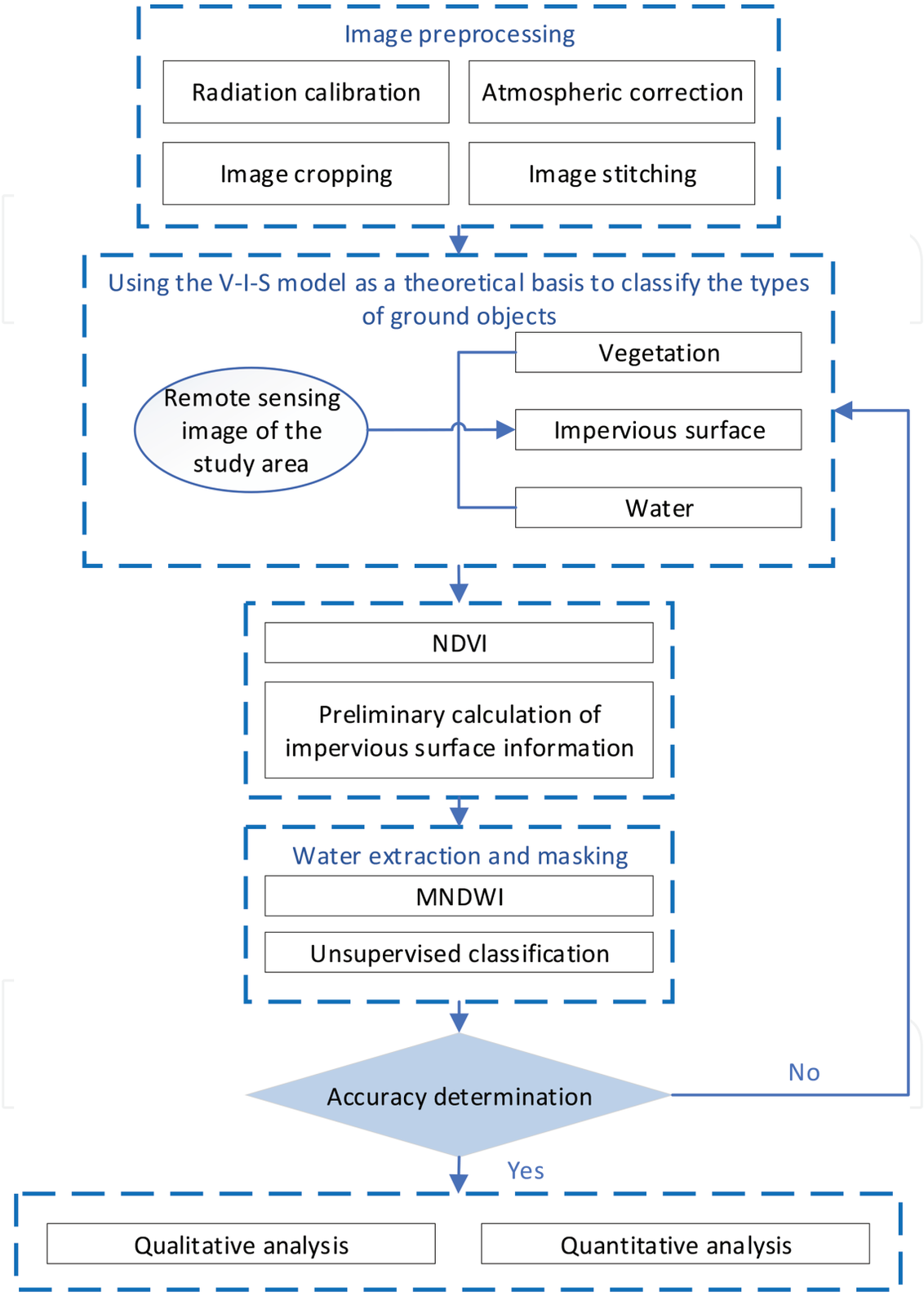


Figure 2. Flowchart of the technical route.

3.2. V-I-S model

In 1995, by analyzing the type of urban land cover, Ridd puts forward the model of surface property composition of urban ecological system and builds the V-I-S model (Vegetation-Impervious Surface-Soil) [10] of urban surface coverage. He supposes that the ground surface of the city is composed of vegetation, water, and soil with different proportions [11]. He suggested that V-I-S model provide the basis for describing biophysical composition of the urban environment and become the basis of further analysis of the urban environment [12, 13]. In this model, if the water surface is ignored, urban coverage can be modeled by soil, impervious surfaces, and the fraction of vegetation. This study is based on the V-I-S model. At the same time, in actual remote sensing images, the surface cover of Lianyungang city is divided into three types: water body, vegetation, and impervious surface, because the bare soil surface is small and negligible. This can be concluded that, with the exception of water, there is a negative correlation between vegetation and water impervious surface in Lianyungang city.

The NDVI (Normalized Difference Vegetation Index) [14–19], also known as biomass index change, makes vegetation to be separated from water and soil. According to the negative correlation between vegetation coverage and impervious surface, this study used vegetation coverage calculation based on NDVI index to extract impervious surface information in Lianyungang city.

The vegetation coverage calculated for the study is based on the standard vegetation index, and its expression is as follows:

$$NDVI = \frac{NIR - Red}{NIR + Red} \tag{1}$$

According to the NDVI, an information map reflecting the vegetation coverage on the ground can be calculated, and the expression of vegetation coverage is as follows:

$$V_c = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}} \tag{2}$$

The region can be approximated as $NDVI_{veg} = NDVI_{max}$, $NDVI_{soil} = NDVI_{min}$, so the formula in the above can be changed to:

$$V_c = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \tag{3}$$

Based on the negative correlation between impervious surface and vegetation, impervious surface can be calculated by the following formula:

$$\mathrm{IS} = 1 - V_c \tag{4}$$

3.3. Improved normalized differential water index (MNDWI) and unsupervised classification

The most common water index is the differential water index (NDWI) [20, 21]. NDWI uses the green belt and near infrared to calculate the difference. This method effectively eliminates vegetation information to highlight moisture but neglects the impact of buildings [22]. Considering the larger urban area in the study area, we chose the improved normalized differential water index (MNDWI). This method utilizes the difference of objects in different bands and highlights the information of the water body through proportional calculations. The formula is as follows:

$$MNDWI = \frac{Green - MIR}{Green + MIR} \tag{5}$$

Unsupervised classification technique, also known as clustering or point group analysis, is defined as the process of searching for similar spectral cluster groups in multispectral remote sensing images and classifying them [23, 24]. According to the distribution of the spectral features of the remote sensing imagery, unsupervised classification technology can distinguish the different types of land features in remote sensing images. At present, the most widely used method in the unsupervised classification is the dynamic clustering method, which mainly includes the K-means mean value algorithm, the heuristic method based on the nearest neighbor rule, and the iterative self-organized data analysis method (ISODATA).

This study combines MNDWI with unsupervised classification algorithms. The water body information image of Lianyungang city was calculated using the MNDWI index, and then, the unsupervised classification algorithm was used to extract the water body vector image and mask processing.

4. Result and discussion

4.1. Accuracy verification

In this study, some reference sample points were randomly selected from the original image. The classification accuracy was evaluated using RMS error. Root mean square error is the deviation between the measured observation and the actual value, and the result must be less than 0.02. In order to quantitatively evaluate the accuracy of the model, the accuracy of the root mean square (RMS) error of the impervious surface gray scale in Lianyungang was tested. The RMSE results for 1987, 1996, 2005, and 2014 are 0.007532, 0.004238, 0.006820, and 0.001956, respectively. All four results are less than 0.02, so the results of this study meet the accuracy requirements.

4.2. Preliminary extraction of impervious surface based on V-I-S model and NDVI index

The main function of NDVI index is to distinguish vegetation from water and soil, and according to the negative correlation between vegetation coverage and impervious surface,

impervious surface information image can be calculated. Through the calculation of remote sensing images of Lianyungang city in 1987, 1996, 2005, and 2014, the vegetation coverage maps of Lianyungang city can be separately obtained.

4.3. Water extraction and mask based on MNDWI index and unsupervised classification

Using the MNDWI index and unsupervised classification algorithm to extract water from remote sensing images in Lianyungang city. First, the center point is randomly selected in the initial image, and the distance from the pixel to the center is calculated. According to the minimum distance rule, it is divided into corresponding category groups. In this study, the maximum number of iterations was set to 15 and the cluster components were divided into 5 categories. Compared with the original remote sensing image, the water group can be clearly identified and the black and white mask image can be extracted. The water obtained through unsupervised classification is shown in **Figure 3**.

4.4. Quantitative estimation of impervious surface

After masking the water body, the final water-impermeable surface map can be obtained. The impervious surface image after the water mask is shown in **Figure 4**. The impervious surface area can be calculated by selecting the appropriate threshold. In this study, the selected thresholds were further tested and evaluated by Google Earth satellite images. In addition, due to the selection of sufficient reference data, a suitable random sampling method was applied. Specific results are presented in **Table 2**.

4.5. Spatial analysis of land use types in Lianyungang city

4.5.1. Analysis on the changing trend of land use types in Lianyungang city

Comparing the impervious surface image with the original image, from the general trend of changes in land use structure, while the impervious surface continues to increase, the area of cultivated land and coastal areas (beach and salt fields) has decreased significantly. From 1987 to 1996, the increased impervious surface was mainly transformed from arable land. From 1996 to 2005, while the continuous decrease of cultivated land, the impervious surface in the coastal area has increased significantly. From 2005 to 2014, the impervious surface in the coastal areas increased more significantly, and the increased impervious surface was mainly composed of coastal beaches and salt fields.

4.5.2. Analysis on driving factors of land use type change in Lianyungang city

4.5.2.1. Natural drivers

From 1987 to 1996, the economic development of Lianyungang city was relatively backward, and the topography was the main factor affecting human agglomeration. During this period, human activities were mainly in the flat terrain. Changes in land use types were mainly caused by the conversion of cultivated land to impervious surface.



Figure 3. Water image.



Figure 4. Impervious surface image.

4.5.2.2. Social and economic drivers

The socio-economic impacts on land use types mainly include population and industry. The increase of the social population is one of the major factors affecting the changes in land use types. The population of Lianyungang increased from 3.2 million in 1987 to 5.3 million in 2014. The large increase in population directly contributed to the increase in impervious surface. In addition, from 1987 to 1996, land use types were mainly concentrated in the first industrial land, and impervious surface changes were mainly concentrated in inland areas. From 1996 to 2005, Lianyungang continued to develop the aquaculture industry while developing the

Years	1987	1996 年	2005 年	2014 年
Percentage (%)	3.17	9.24	23.93	32.87
Area (km²)	181.95	530.38	1373.58	1886.74

Table 2. Dynamic changes information of impervious surface in Lianyungang.

traditional salt industry. Therefore, during the period when Lianyungang's inland impervious surface growth occurred, the impervious surface of the coastal areas also showed more significant changes. From 2005 to 2014, the primary industry in Lianyungang quickly moved to the second and third industries. Under the strategic conditions of "Revitalize the city with the harbor," the tourism industry and the port transportation industry were vigorously developed to realize the integration of the port city and the coastal area.

4.5.2.3. Policy drivers

Since 1984, China has implemented a coastal open policy. Lianyungang city is located in a key strategic development area in China. However, from 1987 to 2005, Lianyungang was unable to give full play to the unique advantages of the port city and did not make full use of characteristic resources. This directly led to the slower economic development of Lianyungang city during this period, and the Land use has outstanding inlandization characteristics. Since 2005, under the conditions of the new national development strategy, Lianyungang has focused on the development and construction of coastal areas, and the type of land use in the coastal areas has undergone major changes.

5. Conclusion

This study used the VIS model, NDVI normalized vegetation index, MNDWI index, and unsupervised classification methods to extract the impervious surface of Lianyungang city. Based on the feature types of Lianyungang city, the image was divided into impervious surface, water body, and vegetation coverage area. Based on this analysis, the changing trend and driving factors of land use types in Lianyungang from 1987 to 2014 were analyzed. The research data show that from 1987 to 2014, the impervious surface of Lianyungang city has increased by 29.7%, and the type of land use has undergone major changes with obvious stage characteristics. The general trend is that the cultivated land and the area along the beach have been greatly reduced, and the impervious area has continued to rise.

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