Water Body Extraction for the Landsat TM Imagery of Hulun Lake

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Abstract: Based on the Landsat TM imagery, several common lake water extraction methods are compared via extracting the Hulun Lake water body. The thresholds in these methods are determined by the Otsu and the Iteration method. It is found that the water area in the image can be extracted using these methods, and the application effects decrease in the order of NDWI, MNDWI, MIR, normal method of spectral relationship. The thresholds determined by the Otsu and the Iteration method are almost equal. The thresholds from Iteration method are more accurate, which means that these two algorithms are feasible in the identification of the lake water body in this region.

1 INTRODUCTION

Since the 1970s, remote sensing technology has been widely used in the extraction of water body information due to its advantages of large monitoring area, short imaging period, and abundant information volume (Cao et al., 2022). Especially, the water body extraction is essential in water resources survey, flood analysis, and environmental monitoring. The accuracy of water body extraction affects the quality of follow-up surveys and assessments. Therefore, it is an attractive topic to extract water bodies from remote sensing images accurately and quickly (Dong et al.,2022; Li et al.,2022).

Considering water accounts for 74% of the Earth's surface, water condition differs under the different geomorphological and hydrological characteristics. Hence, several methods are proposed for extracting water bodies (Anusha et al.,2022; Ma et al.,2007; MaFeeters,1996; McCormack et al.,2022; Lu et al.,2011; Soman and Indu,2022). Zhang, Minghua combine the improved spectral relationship method with the threshold method to construct a multi-conditional spectral relationship model, and used to extract information on the water in the polar high mountains and achieved good results (Zhang,2008). The decision tree is employed in the automatic extraction of the water body (Du et al., 2001; Li and Wang, 2007). Hu, Zhengguang et al. proposes the algorithm based on the AVHRR data combined with the double-boundary extraction and the decomposing of the mixed pixels (Hu et al.,2007). The high accuracy and feasibility of the algorithm is verified in monitoring the lake area changes in northeast of China and Inner Mongolia. Xu, Hanqiu and Cao, Ronglong optimize and improve NDWI separately (Xu, 2006; Cao et al., 2008). Both of them increase the accuracy of water extraction. Although the information extraction methods of water body mainly include single-band threshold method, exponential model method, normal method of spectral relationship, image classification method, and so on, the index method of water body and the normal method of spectral relationship are widely used for water body extraction since their high precision.

The extraction information of lake water body is the basis for the dynamic monitoring of lakes.

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However, due to the complex interaction process among lake water bodies, surrounding land objects, solar radiation, and the atmosphere, the presence of mixed pixels has caused by the multiple interference of mountain shadows and other noises, which makes the extraction difficulty and uncertainty of lake water body increased (Xu et al.,2021). Previous studies have shown that most methods of water extraction have certain regional limitations, such as: the method applied to a certain lake may not be suitable for another lake, and the size of the threshold in the water extraction model has different effects on the extraction results (Sarp and Ozcelik,2017). The thresholds in the existing studies are mostly determined based on experience through repeated human-computer interaction tests, and are rarely determined using a threshold algorithm for image segmentation. The effects of different threshold algorithms on water extraction results are also rarely analysed.

In this study, Landsat TM is used as the data source, and several common water extraction methods are used to extract the water information of the Hulun Lake. This paper compares and analyses the impact of different threshold algorithms on water extraction results, and supports improving the automation of water body information recognition.

2 RESEARCH AREA AND ITS DATA

Hulun Lake (48°30′-49°20′N and 116°58′-117°48′E) lies in the southern suburb of Manzhouli City, Hulunbeier League. Its location is between Xinbarhuzuoqi and Xinbaerhuyouqi, and the lake area belongs to the temperate semi-arid climate zone. The source of the lake water mainly depends on the surface runoff and the atmospheric precipitation. The rivers are flowing into Hulun Lake are mostly seasonal rivers. The main rivers into the lake are the Krulun River in the southwest and the Wuerxun River in the southeast.

The experimental data has taken from the Landsat TM image of September 7, 2010, with a landscape number of 125-26. The product is Level1T, it has been subjected to system radiation correction, ground control point geometry correction, and DEM terrain correction, including 7 bands of data. Data pre-processing is mainly image cropping..

Figure 1: Landsat TM image.

3 LAKE WATER INFORMATION EXTRACTION METHOD

To extract the water body of the Hulun Lake, several common water extraction methods are employed, such like single-band threshold method, normal method of spectral relationship and exponential model method. The threshold required in the above method has determined by a threshold algorithm.

3.1 Water Extraction Method

Based on the single-band threshold method, the water body has a low reflectance in the near infrared and short wave infrared bands, and it has easily distinguished from other features. For this feature, a threshold K can be determined in the TM5 band, the water body is smaller than the threshold, and other features are larger than the threshold.The extraction model of water body is as follows.

$$TM5<K \,. \tag{1}$$

With the normal method of spectral relationship, Zhou, Chenghu et al. analyse the spectral characteristics of ETM+ images. It is found that water has the spectral relationship between TM2+TM3 and TM4+TM5. This feature can be used to extract water information (Zhou et al., 1999). The extraction model of water body is.

$$(TM2+TM3)-(TM4+TM5)>0 . \quad (2)$$

Besides, there are many index models for water extraction, such as the Normalized Difference Water Index (NDWI), the Modified Normalized Difference Water Index (MNDWI), and Normalized Difference Vegetation Index (NDVI). In this study, the formula of NDWI and MNDWI are expressed by:

$$NDWI=(TM2-TM4)/(TM2+TM4), \quad (3)$$

$$MNDWI=(TM2-TM5)/(TM2+TM5). \quad (4)$$

Based on the contrast between the green and near-infrared bands, NDWI can suppress vegetation information to the maximum extent to achieve the purpose of highlighting water information (McFeeters,1996). MNDWI is an improvement to MDWI that better suppresses building information and improves the accuracy of water extraction. The MNDWI and NDWI values of the water body are higher than other ground objects, so the water body information can have extracted by setting the corresponding thresholds for the two indexes. The water extraction models are

$$NDWI>M , \quad (5)$$

$$MNDWI>N , \quad (6)$$

where M and N are threshold values.

3.2 Threshold Algorithm

In order to compare the applicability of different threshold algorithms, the Ostu method and the Iteration method are employed.

The Ostu method is based on the separability of the target and background categories in the image. The basic principle is to divide the grey histogram of the image into two parts with the optimal threshold, such that the inter-class variance between the two parts achieves the maximum value. That is the maximized separation. The Ostu algorithm is expressed as follows.

a. Read the grayscale image.
b. Let k=0, and t(0) be the smallest grayscale value.
c. Divide the image into Class C_o and C_b based on t(k).
d. Calculate the possibility, the mean value and the variance of Class C_o and C_b.
e. Calculate the inter-class variance between of Class C_o and C_b.
f. Let t(k+1)=t(k)+0.005, k=k+1.
g. Repeat Step c-f until t(k) exceeds the largest grayscale value.
h. Find the largest inter-class variance, and the corresponding t(k) is the threshold.

The Iteration algorithm is a method of selecting an appropriate threshold in the image segmentation process, also known as the cyclic threshold method. It is based on the approximation of the idea of threshold iteration, using the program to calculate the appropriate segmentation threshold automatically. The guideline of the Iteration algorithm is as follows.

a. Read the grayscale image, then find the smallest grayscale value t_{min} and the largest grayscale value t_{max}.
b. Let k=0 and $t(0)=(t_{min}+t_{max})/2$.
c. Divide the image into Class C_o and C_b based on t(k).
d. Let t_o be the mean value Class C_o, and t_b be the mean value Class C_b.
e. Let $t(k+1)=(t_o+t_b)/2$ and k=k+1.
g. Repeat Step c-e until $|t(k)-t(k-1)|<0.005$.
h. The last t(k) is the threshold.

According to the former guidelines, the Ostu method and the Iteration method are implemented. For the Ostu method, the threshold initial value t(0) takes the minimum gray value T_{min} of the image and increments by 0.005 steps each time until t(k) is greater than or equal to the maximum gray value T_{max} of the image; A t(k) divides the pixels on the image into two categories. After calculating the variance between the classes in turn, the t (k) when the variance between the classes is the largest has taken as the optimal threshold. In the Iteration method, we first find out the minimum grey value T_{min} and the maximum grey value T_{max} in the image. We can set the average value to T(0), divide the pixels into two categories according to T(0), and calculate the two average grey values of the class pixel, and then the average of the current two average grey values is used as the next threshold, and the process is repeated until $T(k+1)-T(k)<0.005$ ends. T(k+1) at this time is the optimal threshold.

The normal method of spectral relationship (formula (2)) does not need to set a threshold value, and the difference image formed by (TM2+TM3)-(TM4+TM5) has binarized to obtain a water body extraction result. For the single-band threshold method, two thresholds of the TM5 band have obtained by the Ostu method and the Iteration method, so that there are extraction results of water body. The exponential model method needs to obtain NDWI and MNDWI images based on TM images, and then apply the Ostu method and Iteration method to calculate the threshold values, and obtain four extraction results of water body.

4 WATER EXTRACTION RESULTS AND ACCURACY ANALYSIS

On the TM composite pseudo-colour image, the water body is blue-black and the vegetation is bright red or light red. The Visual Image Interpretation has used to delineate the Hulun Lake boundary as a reference data for testing the water extraction results of each method. In order to scientifically and objectively evaluate the experimental results of various methods for extracting water body information, this paper qualitatively and quantitatively evaluates the water body extraction results from two aspects: visual effect and area precision.

4.1 Water Extraction Results

Since the thresholds obtained by the Ostu method and the Iteration method are relatively close, this paper only evaluates the visual effects of the water extraction results obtained by the former.

Figure 2 shows the results of water extraction by each method, and Figure 3 is a partial enlarged view of Figure 2, which is showing the results of water extraction on the south bank of the lake. Referring to the TM composite pseudo-colour image, the shoreline of the east, west, and north shores of Hulun Lake extracted by the single-band threshold method is basically the same as the Visual Image Interpretation, but some of the shoals on the south bank are misunderstood, and there is a large misplacement phenomenon. The extraction result of this method is less than ideal, which has related to the threshold setting on the one hand and the principle of the method on the other hand. The results of the inter-spectral relationship extraction method are more accurate than the single-band threshold method, and there are fewer shoals, which have mentioned mistakenly. The results of NDWI and MNDWI extraction are relatively close. The latter have more shoals, but the rivers in the south eastern shore have extracted well.

In general, the former methods have achieved good results in the obvious east, west and north shores of the water and land boundaries, but the extraction effect on the south bank (Figure 3) is poor, mainly due to the wrong shoal and some high water content. The vegetation area, which also reflects the lower threshold (high) determined by the threshold algorithm.

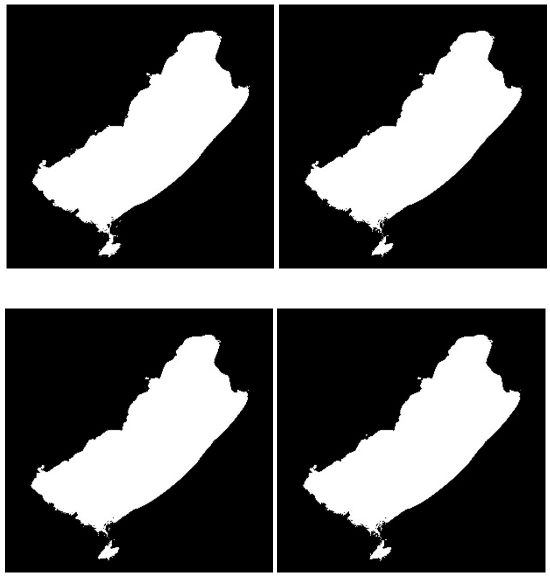

Figure 2: Water extraction results of each method.

Figure 3: Water body extraction results on the south bank of the lake.

4.2 Accuracy Evaluation

The accuracy of the lake surface area obtained by each method has calculated based on the visually interpreted lake area (Table 1). Among them, the area of the three-band threshold method, NDWI and MNDWI is the area when the threshold has determined by the Ostu method. It can be seen that the accuracy of the area obtained by several methods is high, and the order of the area accuracy from high to low is NDWI, MNDWI, normal method of spectral relationship, single-band threshold method. This has consistent with the results of the visual evaluation. At the same time, it has found that the NDWI and MNDWI index models can achieve better results, when the threshold has determined by the automatic thresholding algorithm.

Table 2 shows the thresholds calculated by the Ostu method and Iteration method. It can be seen that for the single-band threshold method, the results obtained by the two threshold algorithms are almost identical; for the two index models NDWI and MNDWI, the difference between the two threshold algorithms is smaller, and the threshold obtained by the Iteration method is more accurate. However, it should have noted that some above extraction methods of water body have mistakenly mentioned a part of the non-water body, and it can be seen that the threshold obtained by the automatic thresholding algorithm is low (high).

Table 1: Comparison of water extraction results of each method.

Method	Area （km^2）	Reference area（km^2）	Area accuracy /%
Single band threshold	1800.95	1772.15	98.37
Inter-spectral relationship	1781.13	1772.15	99.49
NDWI	1775.12	1772.15	99.83
MNDWI	1779.23	1772.15	99.60

Table 2: Threshold calculation results.

Method	Maximum interclass variance method	Iteration method
Single band threshold	57	56
NDWI	0.020	0.025
MNDWI	0.080	0.086

5 CONCLUSIONS

For the Hulun Lake, the NDWI and MNDWI extraction results are better, if the threshold value of water body extraction is determined by the automatic thresholding algorithm. The area of the lake has interpreted visually, and its area accuracy is above 99%. The single-band threshold method is relatively poor. The reason is related to the threshold algorithm. On the other hand, the reason is that it has a great relationship with the principle of the method; the results have extracted by the normal method of spectral relationship, which are between the single-band method and the exponential model method, and the accuracy is high.

In this paper, the lake area extracted by various methods has evaluated quantitatively with the area as a reference index, and the positioning accuracy of each extraction result will have evaluated in the future. In addition, the threshold value obtained by the automatic thresholding algorithm in the study area is different from the artificially extraction threshold set of water body in other areas. The reason for further study has needed, and the result may help to improve the accuracy of the threshold algorithm.

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