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Analysis of changes in water body area during the period of abundant water in Lake Hulun, 2000-2021

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Abstract

Water body area extraction is of great significance in resource management, climate change research, disaster early warning and environmental protection. This paper takes Landsat series remote sensing images as the data source, and uses remote sensing technology to extract and analyze the water body area of Hulun Lake in Hulun Lake National Nature Reserve from 2000 to 2021. The results show that (1) comparing the accuracy of the three water body extraction methods of Support Vector Machine, ISO data and MNDWI, it is found that the MNDWI method has the highest accuracy. (2) During the period of 2000-2021, the lake area of Hulun Lake showed a first decline and then increase, reaching the maximum in 2000 and decreasing to the minimum in 2012, with dramatic changes in the northeastern waters during the period of 2000-2012, and a decrease in the southern waters year by year, but it started to recover from 2016 onwards. (3) The center of gravity migration model analysis shows that the characteristics and patterns of water body boundary changes and migration paths are roughly rectangular. In 2016-2021, the center of gravity migration distance is larger, 12.43km to the northeast. the study shows that: in recent years, Hulun Lake Nature Reserve carries out the ecological environment management and protection of the lake area and the surrounding area, and the environment of the lake area is effectively improved. It is recommended to strengthen water resources management, increase ecological environmental protection, improve the monitoring system, and promote scientific and technological innovation.

Keywords

Supervised classification, unsupervised classification, water body index; Hulun Lake Nature Reserve.

1. Introduction

The size of a water body is an important indicator of the size of the water resources and the quality of the water environment in a lake and its watershed. [1] It is an important indicator of the scale of water resources and the quality of the water environment. By monitoring and analyzing the changes in the area of water bodies, the spatial distribution and temporal changes of water resources can be better understood, providing a scientific basis for water resources management and deployment. Secondly, the impact of climate change on the hydrological cycle can be monitored in real time, providing key data for climate change research. Furthermore, water body area changes are closely related to geologic and hydrologic disasters, which can also be used as an important indicator for assessing the accuracy of climate change model predictions.[2][4] . In recent years, due to the accelerating pace of industrialization and urbanization in China, the natural environment has been deteriorating and water resources have been becoming increasingly scarce. In order to address this problem, it is extremely important to find a more accurate and reliable method to extract the area of the water body so as to grasp the ecological situation of the natural waters.

With the increasing development of remote sensing technology in China, the technical means of water body extraction are becoming more and more mature. From the beginning of the visual interpretation method to the current use of semi-automated or even automated interpretation of images Theory and Methods of Water Extraction Numerous water body extraction theories and methods have been proposed one after another.[4],[6],[7] Jupp and other scholars extracted water bodies in the seventh band of TM images by threshold band state value method, and McFeeters was inspired by Normalized Difference Vegetation Index (NDVI), and explored Normalized Difference Water Index (NDWI).Xu Hanqiu and other scholars innovated the algorithm of MNDWI on the basis of McFeeters's NDWI, which is able to eliminate building information in the water body information better. This method can better eliminate the noise of building information in water body information and improve the accuracy of extracting water body information in towns and cities.[7] Hu Weiguo et al. constructed a decision tree method based on NDVI and NDWI index, which effectively attenuates the influence of thin clouds, snow and ice to a certain extent.[9] The method of decision tree is based on NDVI and NDWI index, and Hu et al. In the face of many different extraction methods, researchers and scholars use various data to verify the extraction methods, such as: Tai Xiaoman et al. extracted and analyzed the applicability of different water body extraction methods from Landsat-8 remote sensing images; Duan Jiwei et al. used different water body extraction methods and analyzed their applicability.[10] Duan Jiwei et al. extracted water body information from TM images by using the threshold method with the chromaticity discrimination method and the ratio measurement method.[11] Duan Jiwei et al. In conclusion, there are many methods to extract water bodies by remote sensing technology. However, in the extraction of water bodies using remote sensing technology, conventional ground survey methods and remote sensing extraction algorithms have different degrees of limitations in the extraction of water body area due to the influence of image data and topographic and geomorphological features of the data. Satellite remote sensing data are widely used in the field of water body area extraction. High-resolution and multispectral remote sensing data provide more accurate data support for water body area extraction, which helps us to better understand and cope with hydrological cycle changes and the challenges they bring.

Hulun Lake Nature Reserve is a comprehensive functional reserve focusing on the protection of national wetland parks and grassland ecosystems, while Hulun Lake, as one of the important lakes in the Inner Mongolia Autonomous Region, the accurate extraction of its water body area is crucial for safeguarding the ecological environment of the lake area and its economic development.[12][13] Hulun Lake is one of the important lakes in Inner Mongolia Autonomous Region. In this context, this paper selects several mainstream extraction methods and combines them with geographic information technology to extract and analyze the area of the lake in the past two decades, in order to provide theoretical and methodological support for the management and protection of Hulun Lake and similar lakes.

2. Materials and Methods

2.1. Overview of the study area

Hulun Lake National Nature Reserve is located in the northeastern part of the Inner Mongolia Autonomous Region of China, in the center of the Hulunbeier Grassland, with a range of 47°45′N-49°20′N, 116°50′E-118°10′E (Figure 1). The reserve covers a total area of 7400 km^2 , including a variety of ecosystems such as grasslands, forests, marshes, rivers, wetlands, etc. in and around Hulun Lake, making it one of the largest watershed reserves in China. Hulun Lake in the reserve is the fifth largest freshwater lake in China and the first largest lake in the northeast region, with an irregular sloping elongated surface[14] The surface of the lake is irregularly slanting and long. The study area is cold in winter and warm in summer, with a large difference between annual and daily temperatures. The mean annual temperature is in the range of -0.6°C to 1.1°C. Precipitation is scarce and concentrated in summer, and the annual precipitation is less than the annual potential evaporation. The annual precipitation is basically in the range of 240.5mm—283.6mm, while the annual evaporation is 455.3mm—1754.3mm.The protected area is in transition from semi-arid to arid zone from east to west and from north to south.

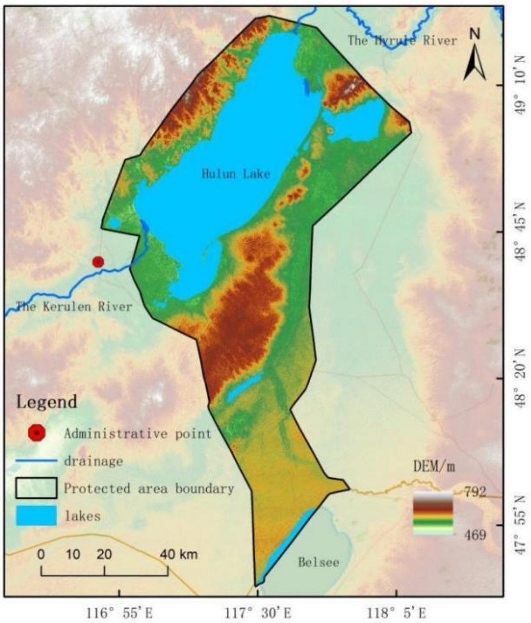

FIG. 1 Location diagram of Hulun Lake National Nature Reserve

2.2. Data sources

In this paper, three types of Landsat TM, ETM+, and OLI images with 30 m spatial resolution and 16 d temporal resolution from the National Aeronautics and Space Administration (NASA) were collected from 2000 to 2021 in the Hulun Lake area. The data are summarized in the following table. With the technical support of 3S, the data units with 125 rows of Landsat 5 TM (2000-2011), Landsat 7 (2012), and Landsat 8 (2013-2021) stripes and 26 rows and less than 25% cloudiness were screened, and the data units were restored, radiometrically calibrated, and atmospherically corrected. After the image data preprocessing, radiation calibration, atmospheric correction, etc., we extracted the information of Hulun Lake's 22-year watershed area and analyzed its spatial and temporal change characteristics through image analysis.The boundaries of the protected areas used in this paper are derived from the Inner Mongolia Hulun Lake National Nature Reserve Administration.

2.3. Research methodology

2.3.1. Supervisory taxonomy

The core of the remote sensing water body extraction method based on spectral supervised classification is to utilize the spectral similarity, i.e., to categorize the image pixels with similar features in the image using many different algorithms. In the paper, Support Vector Machine or SVM, which is the first method of supervised classification, is used to extract the water bodies of Lake Hulun. Support Vector Machine (SVM) is able to automatically discover support vectors with high recognition and differentiation ability to a certain extent, so as to improve the generalization ability and recognition accuracy of the classifier[14] .

2.3.2. Unsupervised classification methods

With the continuous improvement of technical requirements, researchers are no longer satisfied with the manual definition of classification rules to achieve the extraction of water bodies, and envision that the classification rules can be set by the program or the software itself to get rid of the constraints of a large number of human beings to classify, so it produces the remote sensing algorithm of unsupervised classification. Unsupervised classification is based on the characteristics of different features in the image, and computer algorithms are used to analyze the image features statistically, so as to realize automatic classification. In this paper, Iterative Self-Organizing Data Analysize Technique, referred to as (ISO DATA) is used to compute the class means uniformly distributed in the data space[15] The minimum distance technique is used to recalculate the mean values of the iteratively aggregated image elements and then reclassify them according to the new mean values obtained at each iteration of aggregation.

2.3.3. Water body index method

The water body index method is widely used in the field of water body extraction, which is based on the principle of utilizing the reflectivity differences between electromagnetic waves of different wavelengths as well as the elimination of noise components to enhance the band characteristics of water bodies. The modified normalized water body index (MNDWI) is a method based on the reflectivity difference between water bodies and other features in the mid-infrared band, which not only takes into account the factor of suppressing vegetation, but also maximally distinguishes the surrounding buildings and soils, and shows excellent performance in the field of water extraction in the arid zone.[17][18]， [19] Its calculation formula is as follows:

$$\mathrm{MNDWI} = \frac{\mathrm{Green}-\mathrm{Swir1}}{\mathrm{Green}+\mathrm{Swir1}} \qquad \text{(Formula 1)}$$

Where: Green, Swir1 denote the reflectance of the 2nd (0.52-0.60 μm) and 5th (1.55-1.75 μm) bands of the TM (or ETM+) image, and the 3rd (0.525-0.600 μm) and 6th (1.560 -1.660 μm) bands of the OLI image.

In this paper, the waters of Hulun Lake are automatically extracted by using 0 as the threshold value. In the MNDWI image, areas with values greater than 0 are judged as waters[20] . Considering the difference in the area of water bodies between the dry and abundant water periods, and the influence of snow and ice on the results of the study during the dry period, this paper adopts three common water body extraction methods, such as SVM, ISO DATA, and MNDWI, to extract the water bodies of the Hulun Lake region during the abundant water period (May-September), and filters out the most suitable extraction method to be applied in the subsequent analysis of the results.

2.3.4. Accuracy assessment

The classification results of each extraction method cannot reach the degree of complete consistency with the real distribution of features. In order to confirm whether the results of classification and interpretation are accurate, the overall accuracy assessment and spatial consistency test are conducted by constructing the error matrix for the interpretation results of the three extraction methods. The overall accuracies of the following water body and non-water body images that were correctly categorized are expressed as OA, which is calculated as shown in Eq. 2, where the detailed definitions of TP, FP, FN, and TN are shown in Table 1.

$$\mathrm{OA} = \frac{\mathrm{TP}+\mathrm{TN}}{\mathrm{TP}+\mathrm{FN}+\mathrm{FP}+\mathrm{TN}} \qquad \text{(Formula 2)}$$

$$Kappa = \frac{Po-Pe}{1-Pe} \qquad \text{(Formula 3)}$$

Table 1 Example of a confusion matrix

confusion matrix (math.)		projected value	
real value	Term of address	body of water	non-water body
	Body of water	a (TP)	c (FN)
	non-water body	b (FP)	d (TN)

2.3.5. Center of Gravity Migration Model

Traditional machine learning models often face problems such as overfitting and lack of generalization ability when dealing with complex problems. To solve these problems, researchers proposed the Gravity Center Migration Model (GMMl)[21][22] . The model realizes adaptive adjustment during training by tracking the center of data distribution, and is able to reflect the spatial and temporal clustering and migration characteristics of a certain element in the process of spatial change.[23][24] The model can reflect the spatial and temporal clustering and migration characteristics of an element during spatial change. Compared with traditional machine learning methods, the Gravity Center Migration Model has better generalization ability and adaptability.

$$(X_n, Y_n) = \left\{ \frac{\sum_{i=1}^{n} W_i x_i}{\sum_{i=1}^{n} W_i} , \frac{\sum_{i=1}^{n} W_i y_i}{\sum_{i=1}^{n} W_i} \right\} \quad \text{(Formula 4)}$$

Where: Xn and Yn represent the center of gravity coordinates of the water body in different years; Wi is the mean value of the ith raster; xi and yi are the coordinate values of the planar spatial cells; n denotes the time of the study.

3. Results and analysis

3.1. Comparison of the extraction results of the three classifications

In the process of comparative analysis of various water body extraction methods (as shown in Figures 2 and 3), we found that the extraction area obtained by each extraction method is basically consistent. This implies that the various methods have similar efficiency in terms of extracting water bodies. However, in the period from 2018 to 2021, there are large differences in the results obtained between the different extraction methods.

This paper presents a detailed comparative analysis of the three water body extraction methods based on the 2016 Lake Hulun image. In Figure 3, (a), (b) and (c) represent the water bodies of Lake Hulun extracted by supervised classification method, unsupervised classification method and water body index method, respectively. By comparing the results of each water body extraction method, it is found that when encountering a situation where there are more clouds in the image map and they are located above the water body, the two methods, supervised classification method (SVM) and unsupervised classification method (ISO DATA), are only able to categorize the clouds above the water body and the water body, but fail to extract the whole water body, which results in the extracted area being smaller than the actual area. Further analysis shows that supervised and unsupervised classification methods have some limitations when dealing with clouds and water bodies. Clouds and water bodies have similar spectral features in remote sensing images, which makes these two methods prone to misclassification when distinguishing clouds and water bodies. The water body index method, on the other hand, distinguishes water bodies from other features by constructing an index of water body features. Compared with supervised and unsupervised classification methods, the water body index method has higher accuracy in extracting water bodies.

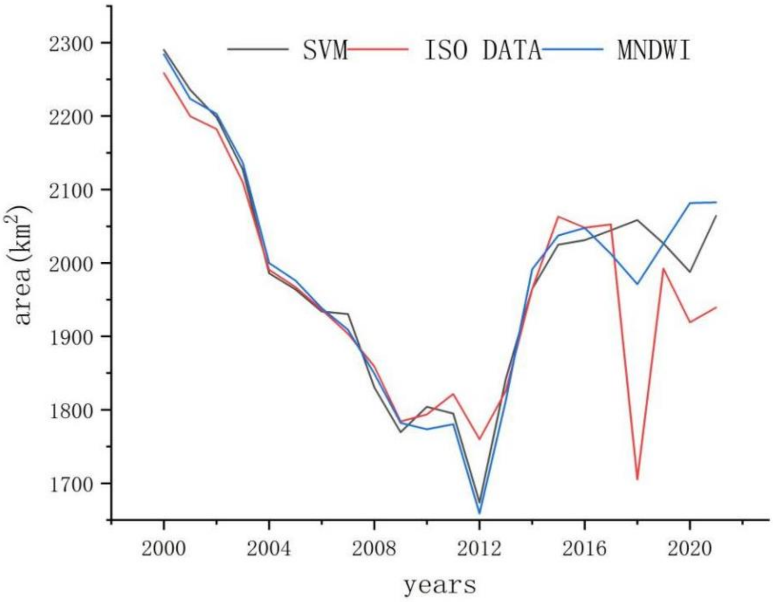

Fig. 2 Comparison of water body areas extracted using different methods

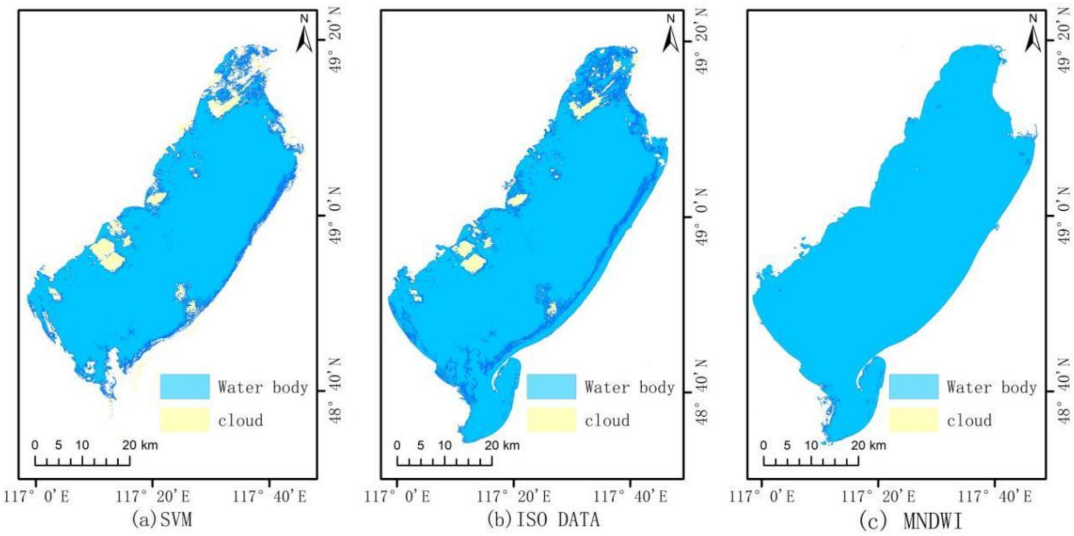

FIG. 3 Comparison of three water extraction methods

The essential difference between the two extraction methods, supervised and unsupervised classification methods, is whether or not training objects are used to extract category knowledge. Supervised classification method in the experimental research area to select a representative training object as a sample, the use of each individual feature parameters to establish a discriminant function to classify the sample image elements. Based on the characteristics of the sample species, other image elements are discriminated and attributed to the type. The advantage is that it can utilize the a priori knowledge to pre-determine the classification category and improve the classification accuracy. However, the disadvantage is that it needs human subjective operation, which requires a lot of manpower and time.

Unsupervised classification method does not need to verify the category as a sample first, the computer automatically discriminates and classifies according to the size of the similarity between the pixels, without human intervention, only need to set the type of discrimination needed to determine the category to which the ground belongs to extract the water body. The advantage is that only the initial parameters can be input to form clusters with unique spectral features, and can discriminate unique categories with small coverage. However, the disadvantage is that without prior knowledge, when there are two kinds of ground features with small differences in spectral features, its recognition efficiency is lower and the classification effect is not as good as the former.

MNDWI-Based on the utilization of the difference in reflectance between water bodies and other features in the mid-infrared band, factors such as suppressing vegetation and maximizing the distinction between surrounding buildings and soils are taken into account. In this process, the mid-infrared band is used instead of the near-infrared band, resulting in an increase in the index of the water body and a decrease in the index of features such as bare land, buildings and cities, thus highlighting the information of the water body and suppressing the information of the features represented by bare land[25] The method is not suitable for the water body and the feature information represented by bare land. However, the limitation of this method is that it is susceptible to the influence of snow, ice and mountain shadows.

3.2. Accuracy assessment of three classification extraction methods

The area of Lake Hulun obtained by the three methods during 22 consecutive years was comparatively analyzed. Calculating the confusion matrix, as shown in Table 2, the overall accuracy of the three water body recognition algorithms reached more than 90%, which demonstrated a high degree of accuracy. Among the three methods, the extraction accuracies are ranked as MNDWI>ISO DATA>SVM in the order of MNDWI (Morphological Difference Water Index) method becomes the optimal choice with its higher extraction accuracy. It is worth noting that although the MNDWI method has the highest extraction accuracy, the other two methods (ISO DATA and SVM) also have some application value.

Table 2 Comparison of accuracy assessment of three water extraction methods, 2000-2021

Precision Evaluation	SVM	ISO DATA	MNDWI
OA	91%	93%	97.5%
Kappa factor	0.89	0.94	0.96

3.3. Analysis of changes in the area of Lake Hulun

3.3.1. Analysis of temporal changes in the water body area of Lake Hulun

The accuracy of MNDWI extraction was higher than that of the other two methods, so the data extracted by this method was chosen. Five sets of data from 2000-2004, 2004-2008, 2008-2012, 2012-2016 and 2016-2021 were used to analyze Lake Hulun's ecological environment for a more in-depth analysis, aiming to reveal the trend of the water body area of Lake Hulun in recent years. Table 3 and Figure 4 show the changes in the water body area of Lake Hulun over five different time periods. It can be seen that the water body area of Lake Hulun has changed considerably between 2000 and 2021. A detailed analysis of these changes is presented below:

Table 3 Changes in the area of water bodies extracted by MNDWI

particular year	Area of water bodies (km^2)	Growth (km^2)	Growth rate in %
2000	2284.23	-284.14	-12.44%
2004	2000.09		
2008	1849.25	-150.84	-7.54%
2012	1658.65	-190.60	-10.31%
2016	2047.69	389.04	23.46%
2021	2082.44	34.75	1.70%

From 2000 to 2004: the area of the water body of Lake Hulun decreased from 2284.23km² to 2000.09km² in 2004, a decrease of 284.14km²and a decrease of 12.44%. This may be due to a variety of factors such as climate change, human activities, etc. during this period.2004 to 2008: the water body area of Lake Hulun further decreased from 2000.09km²in 2004 to 1849.25km² in 2008, a decrease of 150.84km², a decrease of 7.54%. It may be related to the environmental policy at that time, regional economic development and other factors. 2008 to 2012: the area of the water body in Lake Hulun continued to shrink from 1849.25km² to 1658.65km² , a decrease of 190.6km², a decrease of 10.31%. It shows that the environmental problems in this period are getting more and more serious, and measures need to be taken to improve them.2012 to 2016: after a period of treatment and protection, the area of the water body of Lake Hulun began to show a trend of recovery. It increased from 1658.65km² to 2047.69km² in 2016, an increase of 389.04km² or 23.46%. This shows that during this period, the measures taken by our government and relevant departments have achieved some results and the quality of the lake has improved. Finally, in the period from 2016 to 2021, the water body area of Lake Hulun continued to maintain the growth trend, increasing from 2047.69km² to 2082.44km² , an increase of 34.75km² , an increase of 1.70%. This is in line with previous research findings[25][27] This further confirms the effectiveness of the relevant policies and management measures, and the ecological environment of Lake Hulun has been continuously improved.

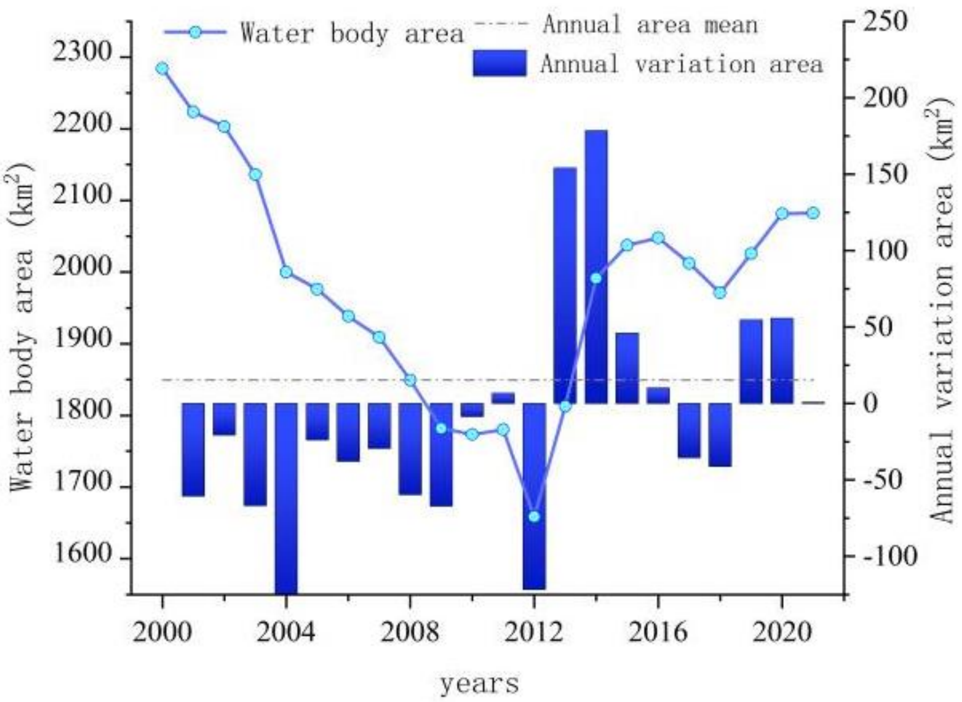

Fig. 4 Change in the area of Lake Hulun water body, 2000-2021

3.3.2. Analysis of spatial changes in the area of Lake Hulun water body

This study analyzed the changes in the watershed area of Lake Hulun and found that the watershed area of Lake Hulun has experienced large fluctuations. Among them, the largest watershed area appeared in 2000, reaching 2284.23 km² , while the smallest watershed area appeared in 2012, only 1658.65km² . Comparing the data of 2000 and 2012, we can clearly see that the watershed area has shrunk by 625.58 km² , which is quite a large reduction in these 12 years. After further study, we found that the period from 2000 to 2012 was the most significant period of dynamic changes in the watershed area of Lake Hulun. During this period, the speed and magnitude of the reduction of the watershed area are incomparable to other periods. Especially in 2004, the northeastern waters of Lake Hulun showed a substantial reduction. By

2008, the waters in this region had almost completely disappeared. At the same time, the waters in the southern region were also decreasing year by year, so much so that in 2012, the waters of the entire Hulun Lake dropped to its lowest point. However, since 2016, the southern waters have gradually begun to recover. Despite this slow process, the watershed area has shown a steady upward trend. By 2021 some of the disappeared areas of the northeastern waters of Lake Hulun have come back to life. Nevertheless, it has not yet recovered to the level of 2000.

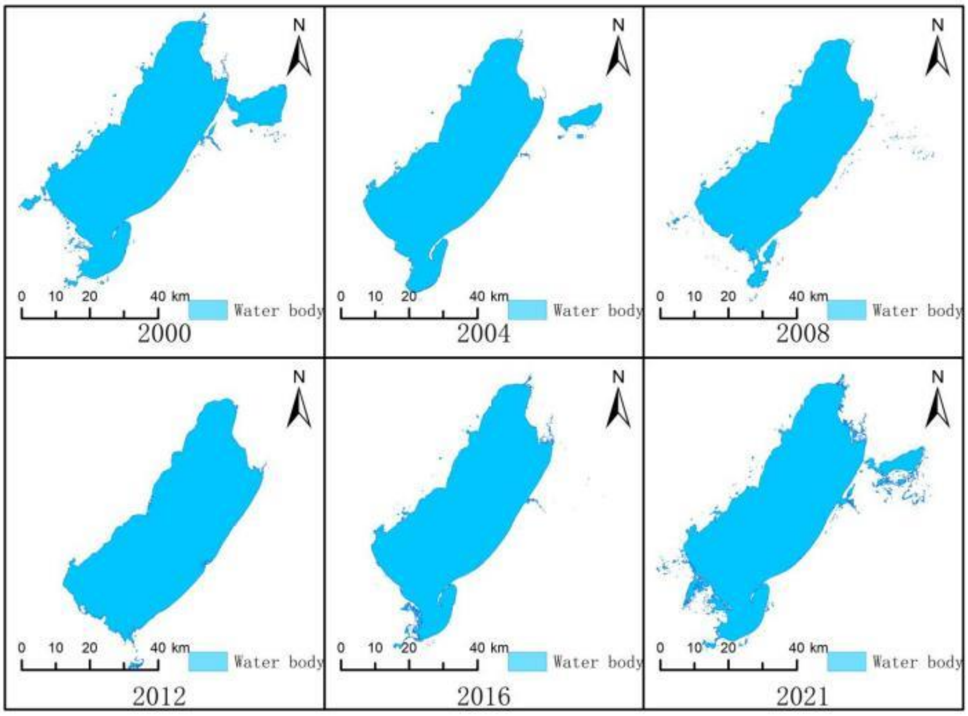

Figure 5 Spatial and temporal variability of water bodies, 2000-2021

In summary, through an in-depth study of the changes in the watershed area of Lake Hulun, we can see that the watershed area of the region has experienced considerable fluctuations over the past decades. In particular, the rapid shrinkage of the watershed area between 2000 and 2012 is a cause for concern. However, the recovery trend since 2016 also gives us hope. In order to protect this precious lake resource, we need to continue to pay attention to and strengthen our research on Lake Hulun so that we can better formulate appropriate conservation measures.

3.4. Water body center of gravity migration process

The center of gravity migration model is an important research method in the field of geospatial analysis. Through this model, the changing law of the water body boundary and its evolution trajectory can be accurately grasped from a spatial perspective. The center of gravity migration path of Lake Hulun in 2000, 2004, 2008, 2012, 2016 and 2021 was calculated and analyzed. The calculation results are shown in Table 4 and Figure 6, and the change process and direction are more complicated. Specifically, the center of gravity migration path of Lake Hulun during the period from 2000 to 2021 presents the following characteristics:

Table 4 Water body center of gravity migration, 2000-2021

the twelve two hour divisions of the day	Migration distance (km)	direction of migration
2000-2004	4.70	southeast
2004-2008	8.45	southwestern
2008-2012	7.92	southwestern
2012-2016	3.14	southeast

2016-2021	12.42	northwest
2000-2021	3.23	northwest

From 2000 to 2004, the center of gravity of Lake Hulun migrated 4.70 km to the southeast, and during this period, the change of the lake body was relatively small, but it started to show a shrinking trend. 2004 to 2008, the center of gravity migrated an increased distance of 8.45 km, and migrated to the southwest. This indicates that the boundary of the water body of Lake Hulun has changed considerably during this period, and the area of the lake has continued to shrink. 2008 to 2012, the center of gravity of Lake Hulun continued to migrate to the southwest, with a migration distance of 7.92 km. During this period, the trend of change of the lake body was similar to that of the previous period. 2012 to 2016, the center of gravity migrated in the direction of change, and migrated to the southeast with a distance of 3.14 km. 2016 to 2021, the center of gravity migrated to the southeast with a distance of 8.45 km. From 2016 to 2021, the center of gravity of Lake Hulun migrated 12.42km to the northeast, with a larger migration distance.For the whole period from 2000 to 2021, the center of gravity of Lake Hulun migrated to the northeast in general, with a migration distance of 3.23km.On the whole, the path of the center of gravity migration is roughly rectangular, and the trend of the change of the boundary of the water body of Lake Hulun has been more obvious in the past 20 years, and it may have certain impacts on the surrounding ecological environment. It may have had a certain impact on the surrounding ecological environment.

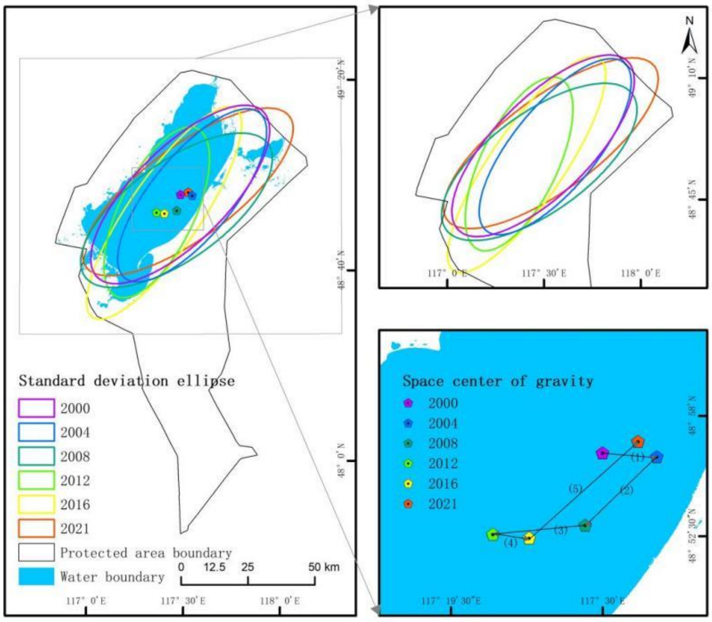

Figure 6 Changes in center of gravity migration of water bodies, 2000-2021

4. Conclusion and discussion

This paper extracts and analyzes the water area of Lake Hulun based on remote sensing technology. Three commonly used water body extraction methods, namely Support Vector Machine, ISO data and MNDWI, were used to extract and verify the accuracy of Hulun Lake water body from 2000 to 2021, and the spatial and temporal changes and migration process of the study area were analyzed. The following conclusions were finally drawn;

Comparative analysis of the results of the three water body extraction methods shows that when there are more clouds in the image and located above the water body, the supervised classification method and the unsupervised classification method can only extract the clouds and the water body above the water body, resulting in the extracted area being smaller than the actual area, and there are limitations of these two methods in dealing with the cloud and water body problem. The water body index method effectively distinguishes water bodies from other features by constructing a water body feature index with higher extraction accuracy.

The extraction accuracy is verified according to the confusion matrix and kappa coefficient, the accuracy of the three methods in the experiment is more than 90%, the kappa coefficient is in the range of 0.89-0.96, and the extraction accuracy is MNDWI>ISO DATA>SVM in descending order.In the practical application, it is possible to choose the appropriate method according to the research purpose, data sources and computational resources to choose the appropriate method. In addition, for different research areas and objectives, it may be necessary to try and optimize multiple methods to find the most suitable extraction algorithm.

From 2000-2021, the lake area of Hulun Lake showed a trend of first decline and then rise, the largest water area in 2000, the smallest in 2012. 12 years of water area shrinkage of 625.58km^2, especially in the northeastern part of the 2000-2012 period the most serious changes in the waters of the 2004 substantial reduction, and In 2008, it almost disappeared. The southern waters decreased year by year, reaching its lowest point in 2012, but began to recover since 2016, and some of the disappeared areas in the northeast also recovered by 2021, but did not reach the 2000 level. Despite fluctuations and decreases in the size of the water body over the past decades, the quality of the lake has gradually improved and the ecosystem has been effectively protected under the management of the government and relevant authorities. Continued attention is still needed to ensure its sustainable development. To this end, it is recommended that water resource management be strengthened, ecological environmental protection be enhanced, the monitoring system be improved and scientific and technological innovation be promoted.

Through the calculation and analysis of the center of gravity migration model, the characteristics and patterns of the water body boundary changes are: from 2000 to 2004, the center of gravity of Lake Hulun moved 4.695km to the southeast; from 2004 to 2008, the center of gravity moved 8.451km to the southwest; from 2008 to 2012, the center of gravity continued to move southwest by 7.915km; 2012-2016, the center of gravity changed to move southeast by 3.142km; 2016-2021, the center of gravity moved northeast by 12.426km, with a large migratory distance; on the whole, the center of gravity migratory path is roughly rectangular.

To summarize, by continuously monitoring the water body area of Lake Hulun, we can better understand the ecological changes of the lake and provide a scientific basis for water resource management and ecological protection. The comparative analysis of the three water body identification algorithms identified the dominant position of the MNDWI method in water body extraction in Lake Hulun. The differences in water body extraction methods may be caused by differences in technical principles, data sources, and algorithms. These differences may have significant impacts in practical applications, so it is crucial for researchers and practitioners to choose appropriate water body extraction methods. From another perspective, this difference also reflects the dynamics and complexity of the field of water body extraction. With the continuous development of science and technology, new extraction methods and techniques are emerging, and how to apply these methods to practical scenarios and select and optimize among multiple methods has become an important challenge in the field of water body extraction. To address this issue, the advantages and disadvantages of various water body extraction methods need to be studied in depth, and their applicability in different regions and scenarios needs to be explored. In addition, it is also necessary to pay attention to the latest international research developments, strengthen academic exchanges and cooperation at home and abroad, and pay attention to the development and application of other water body extraction methods. In the future research, we will use this as the basis for continuing to explore and optimize the water body extraction methods, further exploring the ecological changes of

Lake Hulun and its influencing factors, and better serving the water resources protection and lake ecological research.

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