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Analysis of LULC Changes in Hongze Lake Catchment from 2013 to 2023 Based on Remote Sensing

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Abstract:

As the fourth largest freshwater lake in China, the study of land use and land cover (LULC) changes in Hongze Lake Catchment is useful for monitoring the impact of urbanization on the local ecological environment. In this paper, Landsat 8 satellite remote sensing images from 2013 and 2023 were used to analyze its LULC. Key findings indicate: (1) The land cover type of Hongze Lake Catchment changed significantly from 2013 to 2023, with an increase in the area of built-up land, grassland and permanent water bodies, and a decrease in the area of bare/sparse vegetation, cropland, herbaceous wetland and tree cover. The area of wetlands changed the most, decreasing by 438.4 square kilometers. (2) Accuracy assessment showed an overall accuracy of 0.7553 and a Kappa coefficient of 0.6324. (3) Urbanization development, population growth, and the expansion of local aquaculture were the main reasons for LULC changes. This study can provide a scientific basis for environmental monitoring, land management, and ecological conservation strategies in the Hongze Lake Catchment.

Keywords: Land use and land cover; remote sensing; change analysis; ecology

1. Introduction

Hongze Lake is the fourth largest freshwater lake in China, serving as a critical storage lake for the Eastern Route of the South-to-North Water Diversion Project. Located in the middle and lower reaches of the Huai River Basin, it is the largest plain-type reservoir in the region.

As an important ecological barrier in the Huai River basin, Hongze Lake not only undertakes the functions of flood control, irrigation and navigation but also has a rich biodiversity. In recent years, with the rapid socio-economic development and urbanization in China, the ecological land use in the Hongze Lake Catchment has faced severe challenges. The land use structure has changed significantly, and the area of natural wetlands has been drastically reduced [1]. This will further lead to the weakening of the ecological regulation ability, the shrinking of biological habitats, and the increasing risk of flooding and

water pollution. Therefore, dynamic monitoring of land use and land cover (LULC) changes in the Hongze Lake Catchment with the help of remote sensing technology is of great significance in timely grasping the trend of ecological environment evolution, accurately identifying the needs for land use restructuring and realizing regional sustainable development.

Remote sensing technology is conducive to large-scale and efficient acquisition of surface information and can quickly capture the details of changes such as wetland shrinkage and urban expansion. Recently, many scholars have carried out extensive studies on LULC based on remote sensing data and have derived many conclusions of practical significance. Mustapha et al. and Selmy et al. respectively used remote sensing satellite imagery to monitor and assess the LULC changes in Fez of Morocco and Sohagah Governorate of Egypt, and analyzed the effect of drought on the changes [2, 3]. Feng et al. and Darem et al. used multi-temporal satellite imagery and LULC classification methods to respectively analyze the regional environmental changes in the Khushab and Bakar districts of Punjab and northern Saudi Arabia [4, 5]. Joshi et al. assessed the LULC changes due to industrialization in northern Chhattisgarh using remote sensing techniques [6]. Zheng and Chen et al. concluded from satellite datasets that the construction land in Tianjin mainly originated from the conversion of cropland and grassland [7].

Based on the above research background, this study aims to select a supervised classification method to assess the LULC of Hongze Lake Catchment in 2013 and 2023 using Landsat 8 satellite remote sensing images. By analyzing the LULC changes in the Hongze Lake Catchment over a decade, this paper reveals the negative impacts of urban development on the ecosystem.

2. Data and Methods

2.1 Overview of the Study Area

Hongze Lake is one of the five largest freshwater lakes in China, which is located in the lower reaches of the Huai River in the western part of Jiangsu Province, China, at the junction of Huai'an City and Suqian City. It is 65 kilometers long and 24.4 kilometers wide, with an average depth of 1.5 meters, a surface area of about 2069 square kilometers, and wide variations in water level [8]. As the largest wetland in the Huai River Basin, Hongze Lake is not only an important water source for the neighboring areas but also plays an important role in flood and drought control, soil and water conservation, climate regulation, and biodiversity protection. The Hongze Lake Catchment studied in this paper is between 32°45'N and 33°50'N and between 118°15'E and 119°10'E (Fig. 1).

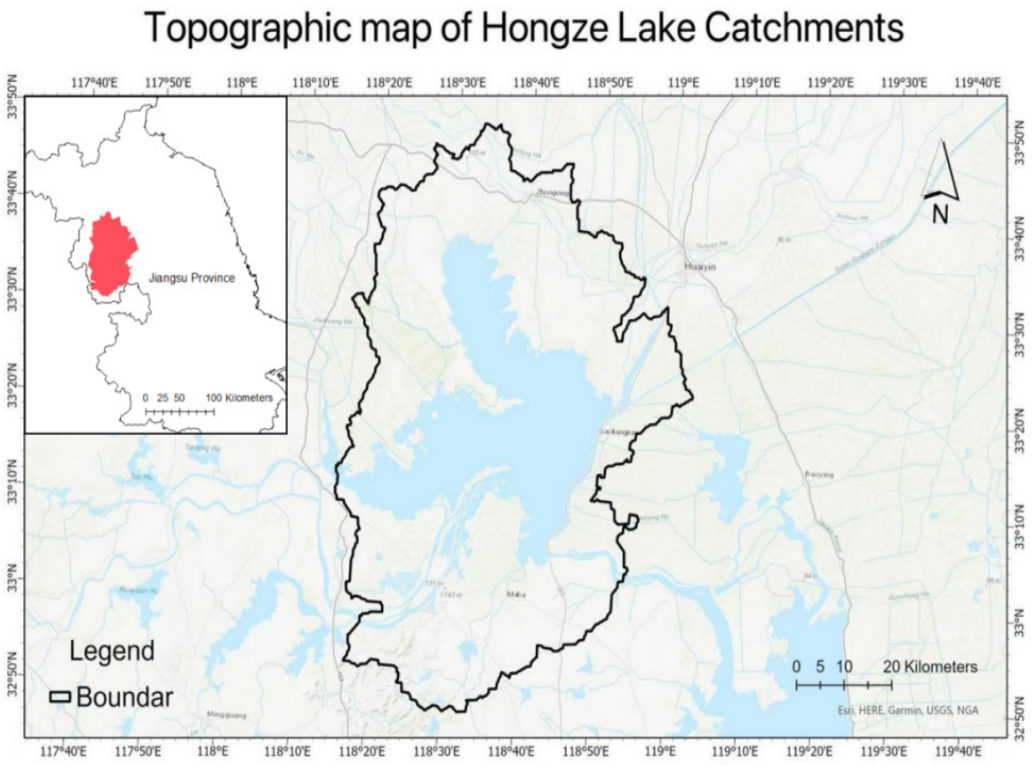

Fig. 1 Topographic map of Hongze Lake Catchment

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2.2 Data Source

In this study, Landsat 8 satellite remote sensing images from November 15, 2013, and November 27, 2023, were imported. The base and final years of the datasets exhibited low cloud coverage, and the acquisition dates were proximate to minimize seasonal variability effects. This study selected spectral bands corresponding to the red, green, and blue color channels, where different band combinations could generate color composites to highlight distinct land cover types, serving as the basis for supervised classification. Sentinel-2 satellite images provide existing classified ESA land cover maps with high spatial resolution, which are imported in this paper to be used as reference maps. Table 1 presents the datasets employed in this study.

Table 1. Research datasets

Raw data	Time	Format	Resolution	Coordinate system	Source
Landsat 8	2013.11.15	TIFF	30x30m	WGS_1984_UTM_Zone_50N	https://earthexplorer.usgs.gov
Landsat 8	2023.11.27	TIFF	30x30m	WGS_1984_UTM_Zone_50N	https://earthexplorer.usgs.gov
Sentinel-2	2021	TIFF	10x10m	GCS_WGS_1984	https://esa-worldcover.org/en

2.3 Research Methods

2.3.1 Supervised Classification Method

The supervised classification method adopted in this study is a remote sensing data processing technique that trains a classifier based on known category samples and then uses the classifier to automatically classify pixels in data such as remote sensing images. It can realize precise classification of remote sensing data, and the classification process is highly targeted and manipulable. According to the ESA global land cover classes, this paper divides the study area into seven classes: tree cover, grassland, cropland, built-up, bare ground/sparse vegetation, permanent water bodies and herbaceous wetlands. A certain number of land cover-type samples are manually selected from Landsat 8 satellite images to develop training sites. The computer compares each pixel with the training samples and classifies it into the most similar sample class according to different rules.

2.3.2 Confusion Matrix

A confusion matrix is a table used to evaluate the performance of a classification model, where the rows represent the true classes and the columns represent the predicted classes. Common metrics for assessing classification accuracy include overall accuracy and the Kappa coefficient. Assuming that there are k classes in total, and n samples are randomly selected, where i denotes the row index (i = 1, ..., k) and j denotes the column index (j = 1, ..., k). Overall accuracy refers to the proportion of correctly classified samples out of the total number of samples [9], calculated as:

$$Overallaccuracy\left(OA\right)=\frac{\sum_{i=1}^{k}n_{ii}}{n} \tag{1}$$

Kappa coefficient is an index to measure the difference between the consistency of the classification results and the randomized classification, the closer the value is to 1, the higher the consistency [10], calculated as:

$$Kappacoefficient\left(k\right)=\frac{OA-P_c}{1-P_c} \tag{2}$$

$$P_c=\frac{\sum_{i=1}^{k}n_{+1}n_{i+}}{n^2} \tag{3}$$

Among them, n+i and ni+ represent the total values of each column and each row respectively. In this study, 94 random points were created on the LULC map of the final year and compared with the actual cover types in the reference map to generate a confusion matrix. The overall accuracy and Kappa coefficient were then calculated to verify the cartographic accuracy.

3. Results

Fig. 2 shows the LULC maps of the Hongze Lake Catchment in 2013 and 2023. The land cover types in the catchment are dominated by cropland and permanent water bodies, with bare/sparse vegetation having the smallest area. The distribution of grassland and bare/sparse vegetation are scattered, while most built-up areas are concentrated, especially along lakes and rivers. In 2013, herbaceous wetlands were mainly distributed along the Hongze Lake, but the area of wetlands decreased significantly in 2023.

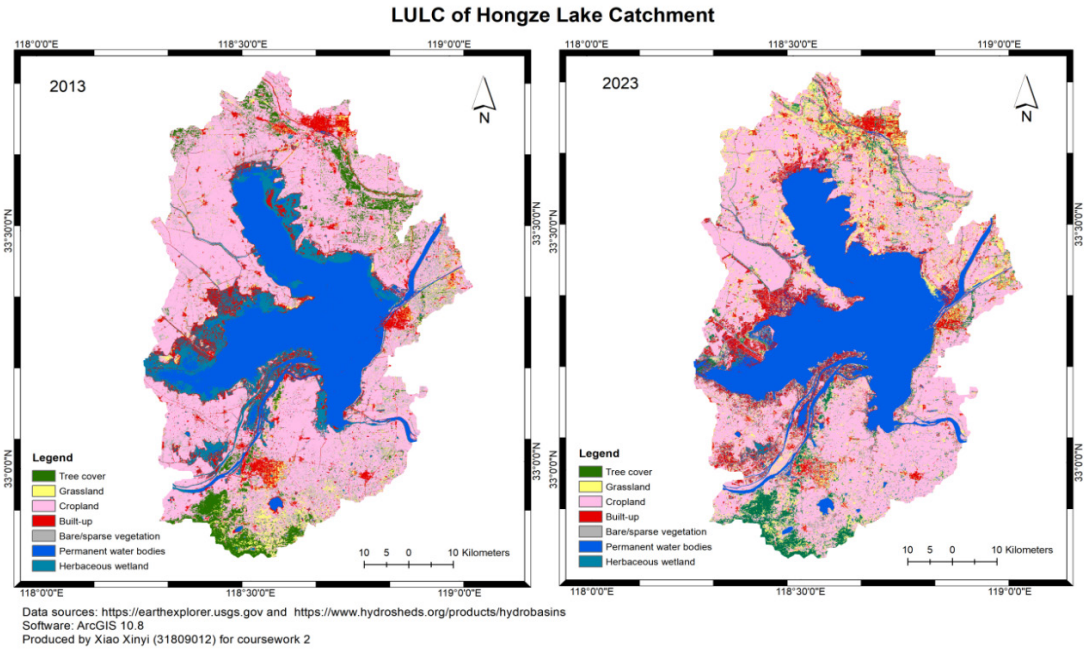

Fig. 2 LULC map of Hongze Lake Catchment in 2013 and 2023

The comparison of the area of various land types in 2013 and 2023 shows that the LULC in Hongze Lake Catchment has changed significantly over the past decade (Table 2). In this decade, the expansion of built-up land in the Hongze Lake catchment has been particularly evident along lakes and rivers, reflecting the land demand caused by urbanization and population growth. The area of permanent water bodies increased by 307.64 square kilometers, and the expansion of water bodies is related to the degradation of wetlands and the development of artificial waters. The grassland area has increased by 138.92%, which is the largest increase among all land types, and it is related to the local ecological fallow or natural vegetation succession.

In contrast, cropland and tree cover decreased by 112.10 square kilometers and 16.32 square kilometers, respectively, which is related to urban expansion and industrial restructuring. The decrease in bare/sparse vegetation was smaller, reflecting the higher stability and lower degree of development of this land type. Notably, the area of herbaceous wetland plummeted from 479.41 square kilometers to 41.01 square kilometers, showing a reduction of 438.4 square kilometers and a drastic decline of 91.45%, which is the most severe. This indicates that the degradation of the wetland ecosystems is particularly prominent, directly threatening the ecological function of the catchment and its biodiversity. These changes collectively reflect the profound impacts of urban expansion, agricultural restructuring, and the development of aquaculture on this catchment's land use pattern.

Table 2. LULC areas of Hongze Lake Catchment in 2013 and 2023 and area changes

Area (square kilometers)							
	Bare land/sparse vegetation	Built-up	Cropland	Grassland	Herbaceous wetland	Permanent water body	Tree cover
2013	263.36	448.44	2586.31	197.78	479.41	1111.21	302.71
2023	256.62	471.59	2474.21	470.55	41.01	1418.85	286.39
Change	-6.74	23.15	-112.10	272.77	-438.4	307.64	-16.32

For accuracy assessment, this study took random points as samples on the 2023 LULC map, and used the 2021 LULC map of Hongze Lake Catchment as the reference map (Fig. 3). Calculated by the confusion matrix, the overall accuracy was 0.7553 and the Kappa coefficient was 0.6324, which was a relatively accurate result (Table 3). The overall accuracy value of 0.7553 instead of 1 indicates that there is still a change in LULC in the Hongze

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Lake Catchment between 2021 and 2023, further supporting the description of the LULC change results between the base year and the final year.

Table 3. Accuracy assessment

	Bare land/sparse vegetation	Built-up	Cropland	Grassland	Herbaceous wetland	Tree cover	Total
Bare land/sparse vegetation	1					1	2
Built-up		2	2	1	2	1	8
Cropland			40	4		3	47
Grassland			4	2	1	3	10
Herbaceous wetland			1		23		24
Tree cover						3	3
Total	1	2	47	7	26	11	94
Overall accuracy	0.7553						
Kappa coefficient	0.6324						

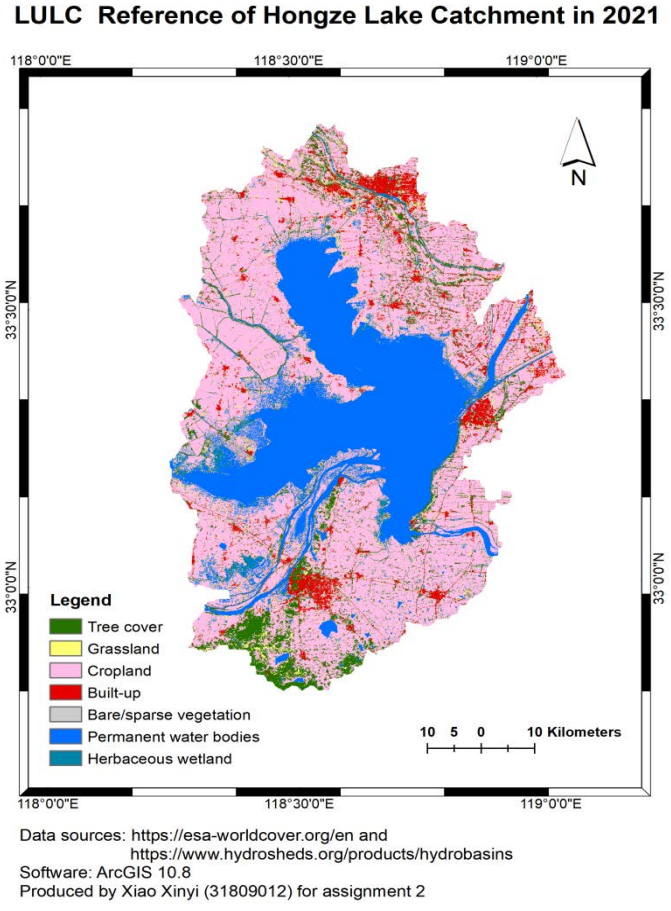

Fig. 3 LULC map of Hongze Lake Catchment in 2021 (reference map)

4. Discussion

From 2013 to 2023, there is a significant increase in built-up land in Hongze Lake Catchment, especially along the lake. This is because with urbanization and population growth, more built-up areas are needed to meet human production activities and residential needs. As the fourth largest freshwater lake in China, Hongze Lake has high-quality water resources that provide a favorable growing environment for the Chinese Lianfinger crab. As a result, the local aquaculture industry has developed rapidly, especially in the northern and western parts of Hongze Lake, which has become another reason for the increase in built-up land. In addition, the concomitant development of urbanization and lakeshore industries has led to the loss of forests and herbaceous wetlands, further affecting water runoff and habitats. Along with economic development, these changes in land cover types have brought about ecological damage. Among them, the reduction of tree cover will further affect carbon sinks and biodiversity. Significant reductions in the area of natural wetlands may have led to a decline in biodiversity as well as functional degradation in ecosystem services.

In order to guarantee the water quality safety of the South-to-North Water Diversion Project and promote the sustainable economic development of the Huai River Basin, the ecological protection of Hongze Lake needs to be advanced in stages. Currently, the focus of governance is to coordinate the relationship between planting, breeding, and water protection, scientifically demarcate the water level line, vigorously promote the project of returning fields to the lake, and curb the trend of ecological degradation. In the medium-term restoration stage, the government should formulate policies to systematically carry out the ecological restoration of the lakeside zone, build ecological buffer zones, strictly protect natural wetlands, and gradually restore ecological functions. For long-term protection, natural resources and biodiversity should be protected through the establishment of nature reserves, and the comprehensive restoration of wetland ecological functions should be continuously promoted. However, this study still has limitations that need to be improved in certain aspects.

From the LULC maps of 2013 and 2023, there are some differences in land cover types, but the accuracy is relatively high, which may be due to the uneven distribution of random points on different types of regions. Since the majority of land types in Hongze Lake Catchment are permanent water bodies and cropland, the random points have a higher probability of falling on these two types, and even no points are generated in the herbaceous wetland area. However, these two types are larger and less variable over the years, so the overall accuracy and Kappa coefficient calculated in this study may be slightly higher than the actual values.

In the future, with the continuous innovation of remote sensing technology, satellite data with higher resolution and more spectral bands will provide more precise information for research. By utilizing these advanced data, it will be possible to deeply analyse the microscopic processes of LULC change, understand the structural changes within the land, and how these microscopic changes affect the material cycle and energy flow of ecosystems at the macro level.

5. Conclusion

This study used Landsat 8 satellite data and ESA land classification basis to classify the LULC in the Hongze Lake catchment using a supervised approach, and further made a change analysis. It was found that the land cover types in this catchment changed significantly from 2013 to 2023 with the development of urbanization and local aquaculture. Among them, the area of herbaceous wetlands decreases most drastically from 479.41 square kilometers to 41.01 square kilometers, a drop as high as 91.45%, due to the expansion of local urbanization and the development of aquaculture. On the contrary, the area of permanent water bodies increased the most, with 307.64 square kilometers, and the expansion of water bodies reflected the impacts of wetland degradation and artificial water development.

This study is conducive to monitoring and assessing environmental changes in the Hongze Lake Basin, formulating effective land management and protection strategies to maintain biodiversity, and achieving regional sustainable development. However, the study has certain limitations. For example, the uneven distribution of random points in the accuracy assessment may lead to inflated results. In the future, accuracy can be improved by manually distributing points uniformly. Additionally, combining higher-resolution satellite data can enable in-depth analysis of the micro-mechanisms of land use changes and their profound impacts on ecosystems, providing more precise scientific support for the sustainable development of the catchment.

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