ISSN: 2414-1895 DOI: 10.6919/ICJE.202505_11(5).0007

Dynamic Analysis of Water Area Change in Baiyangdian Wetland based on Landsat Imagery

Lin Dong, Mo Zhao, Zishuo Hu, Zeming Liu, Xiaoyu Pi, Mengqian Li*

North China University of Science and Technology, Tangshan 063210, China

Abstract

Baiyangdian is the largest freshwater wetland ecosystem in the North China Plain. Driven by the South-to-North Water Diversion Project, dredging and dredging, and the Hundred Precipitates Linkage Project, Baiyangdian has implemented scientific ecological water replenishment, and the amount and level of water in the precipitate have gradually increased, and the condition of the water bodies has significantly improved. In order to study the change of Baiyangdian water area in recent years, the study is based on Landsat remote sensing image data, using the water body index method to extract the water body in Baiyangdian region from 2003 to 2023, evaluating the extraction accuracy of each water body index, selecting the most suitable water body index for Baiyangdian region, and analyzing the change of Baiyangdian water area and driving factors during this period. The study shows that NDWI is a water body index method with higher extraction accuracy and is more suitable for Baiyangdian region, and the overall expansion trend of Baiyangdian watershed area from 2003 to 2023. The results of the study can reflect to a certain extent the change of Baiyangdian water area in recent years, and can provide reference for the management of Baiyangdian water bodies.

Keywords

Baiyangdian Wetland; Water Index Method; Accuracy Assessment; Changes in Water Area.

1. Introduction

Baiyangdian is China's largest lake on the river-sea plain and a typical lake-type wetland in North China. It plays a key role in climate regulation, water conservation, flood control, and biodiversity protection. However, due to global warming and increased human demand for natural resources, the water inflow to Baiyangdian has decreased, leading to ecological crises like water shortages, shrinking lake areas, and frequent dry lake beds. Therefore, accurately and quickly monitoring the dynamic changes in Baiyangdian's water area and understanding the driving factors is of great significance.

Remote sensing technology, with its capabilities of rapid information acquisition, large-area synchronous observation, and high timeliness, is widely used in lake water body dynamic monitoring, water resource changes, and flood disasters. The spectrum analysis method is commonly used for water body extraction. For example, Zhang Qing et al. used the Normalized Difference Water Index (*NDWI*) based on GF-1 image data to extract and study the water body of Kyaigar Glacier Lake, achieving over 90% suppression of non-water information[4]. Li Xinyue et al. developed the Revised Normalized Difference Index (*RNDWI*) to extract urban flood ranges, making water boundaries clearer[5]. Fu Baoqing et al. used the Enhanced Water Index (*EWI*) based on Landsat images to extract large lake water bodies in Jiujiang City and analyze water area changes and driving factors[6]. Qiu Huang'ao et al. used the New Water Index (*NWI*) to extract water bodies in Poyang Lake and

ISSN: 2414-1895 DOI: 10.6919/ICJE.202505_11(5).0007

nearby areas, with good suppression of vegetation and information, and high extraction accuracy[7]. However, due to spectral differences of the same object in different geographical environments, no single water index is suitable for all areas, and their applicability varies. Previous studies on Baiyangdian mainly focused on the impacts of ecological water replenishment on vegetation patterns and ecosystem services, with less research on water body changes and driving factors[9-10]. Additionally, Baiyangdian has rich vegetation and other interference factors affecting water body extraction, and insufficient research on the applicability of water indices in this area. Therefore, this study uses Landsat remote sensing image data from 2003 to 2023, applies five typical water indices to extract water bodies in Baiyangdian, evaluates their extraction accuracy, selects the highest-accuracy index for annual water body extraction, analyzes the spatial-temporal changes in water area, and examines the driving factors related to temperature, precipitation, evaporation, humidity, and vegetation cover, providing suggestions for water resource management and ecological protection in Baiyangdian.

2. Research Area Overview and Data Sources

2.1 Research Area Overview

Baiyangdian is located in central Hebei Province, within Anxin County, Baoding City. Situated in a low-lying area between the Yongding River alluvial fan and the Huaihe River alluvial fan, it belongs to the Haihe River Basin and is the largest freshwater lake in North China. It plays important roles in water storage, flood control, irrigation, and maintaining ecological balance, known as the "Kidney of North China." Its geographic range is 115°38′-116°07′E, 38°43′-39°02′N. Driven by projects like the South-to-North Water Diversion Project, Yellow River water diversion, and reservoir replenishment, Baiyangdian has implemented scientific ecological water replenishment, leading to increased water volume and level, enhanced water environment capacity, and restored ecological scenery.

2.2 Data Sources and Processing

This study uses Landsat 5 TM or Landsat 8 OLI remote sensing image data from 2003, 2007, 2011, 2015, 2019, and 2023, covering Baiyangdian's flood season with low cloud cover. Data from the same period in different years are selected to avoid inaccuracies in water body extraction and water area change analysis during dry seasons. Preprocessing includes radiometric calibration and atmospheric correction to reduce radiation errors and atmospheric impacts on surface reflection.

3. Research Methods

3.1 Water Body Extraction Method

McFeeters developed NDWI based on water's spectral characteristics, using its high reflectance in the green band and strong absorption in the near-infrared band to extract water bodies precisely[11]. Subsequent studies improved this index. Xu Hanqiu proposed MNDWI using the mid-infrared band instead of the near-infrared band in NDWI to enhance the differentiation between water and soil and extract water bodies effectively[12]. EWI was created to distinguish semi-dry rivers from residential areas and soil in semi-arid regions, enabling complete water body extraction[13]. Ding Feng developed NWI based on water's strong absorption in the near-infrared and mid-infrared bands and lower reflectance than non-water objects like soil, vegetation, and buildings[14]. RNDWI, constructed using short-wave infrared and red light bands, weakens mixed pixel and mountain shadow effects, precisely extracts water-land boundaries, and can even identify narrow water bodies[15]. Specific index formulas are shown in Table 1:

ISSN: 2414-1895 DOI: 10.6919/ICJE.202505_11(5).0007

Table 1. Formulas for Calculating Water Indices

Index Name	Formula	**Explanation of Symbols in the Formula**
NDWI	$NDWI=\frac{\rho_G-\rho_{NIR}}{\rho_G+\rho_{NIR}}$	ρ_G is the reflectivity of the green band in the remote sensing image; ρ_B is the reflectivity of the blue band in the remote sensing image; ρ_R is the reflectivity of the red band in the remote sensing image; ρ_{NIR} is the reflectivity of the near-infrared band in the remote sensing image; ρ_{MIR} is the reflectivity of the mid-infrared band in the remote sensing image; ρ_{SWIR} is the reflectivity of the short-wave infrared band in the remote sensing image.
MNDWI	$MNDWI=\frac{\rho_G-\rho_{MIR}}{\rho_G+\rho_{MIR}}$	
EWI	$EWI=\frac{\rho_G-\rho_{NIR}-\rho_{MIR}}{\rho_G+\rho_{NIR}+\rho_{MIR}}$	
NWI	$NWI=\frac{\rho_B-(\rho_{NIR}+\rho_{MIR}+\rho_{SWIR})}{\rho_B+(\rho_{NIR}+\rho_{MIR}+\rho_{SWIR})}$	
RNDWI	$RNDWI=\frac{\rho_{SWIR}-\rho_R}{\rho_{SWIR}+\rho_R}$	

3.2 Water Body Extraction Method

Accuracy assessment is the main indicator and theoretical basis for evaluating the quality of water body extraction methods in remote sensing monitoring [16]. In this study, five typical water body indices were selected to extract water bodies in the Baiyangdian area. Taking the Landsat remote sensing image of Baiyangdian in 2019 as an example, as shown in Figure 1, combined with high-resolution remote sensing image data of the same period, random samples were selected through visual interpretation to establish a verification sample dataset. Then, this verification sample was combined with the extracted water bodies of the study area in that year. The confusion matrix was used to evaluate the accuracy of water body extraction by each water body index, and various classification accuracy indicators were calculated, including overall accuracy, *Kappa* coefficient, mapping accuracy, and user accuracy. The specific results are shown in Table 2.

As can be seen from Table 2, among the five selected water body index extraction models, *NWI* has the lowest overall classification accuracy and Kappa coefficient, which are 85.46% and 0.685, respectively. Moreover, its mapping accuracy, user accuracy, commission error, and omission error are also at the lower levels among the five water body indices, indicating that the extraction accuracy of water bodies in the study area using *NWI* is relatively low. The omission error of *MNDW*I is the largest among the five water body indices, reaching 11.82%, suggesting that when using this water body index to extract water bodies in the study area, some non-water body fragments are easily misclassified as water bodies, reducing the accuracy of water body extraction. The commission error of *RNDWI* is the largest among the five water body indices, reaching 11.89%, indicating that when using this water body index to extract water bodies in the study area, non-water body targets are easily misidentified as water bodies, affecting the accuracy of water body extraction. *EWI* performs relatively well in all accuracy assessment indicators and can extract water bodies in the study area relatively well. However, compared with *NDWI*, its omission probability is too high, affecting the completeness of water body extraction, and its overall accuracy and *Kappa* coefficient are also lower. *NDWI* has the highest values in all accuracy indicators among the five water body indices, and it can extract water bodies more completely with the lowest commission and omission probabilities.

Considering all accuracy indicators comprehensively, it can be concluded that the order of water body extraction accuracy of the five water body indices in the Baiyangdian area in 2019 is: *NDWI* > *EWI* > *RNDWI* > *MNDWI* > *NWI*. Based on the above accuracy assessment results of each water body index, the normalized difference water body index *NDWI* with the highest classification accuracy was selected to extract water bodies in each period from 2003 to 2023 in the study area.

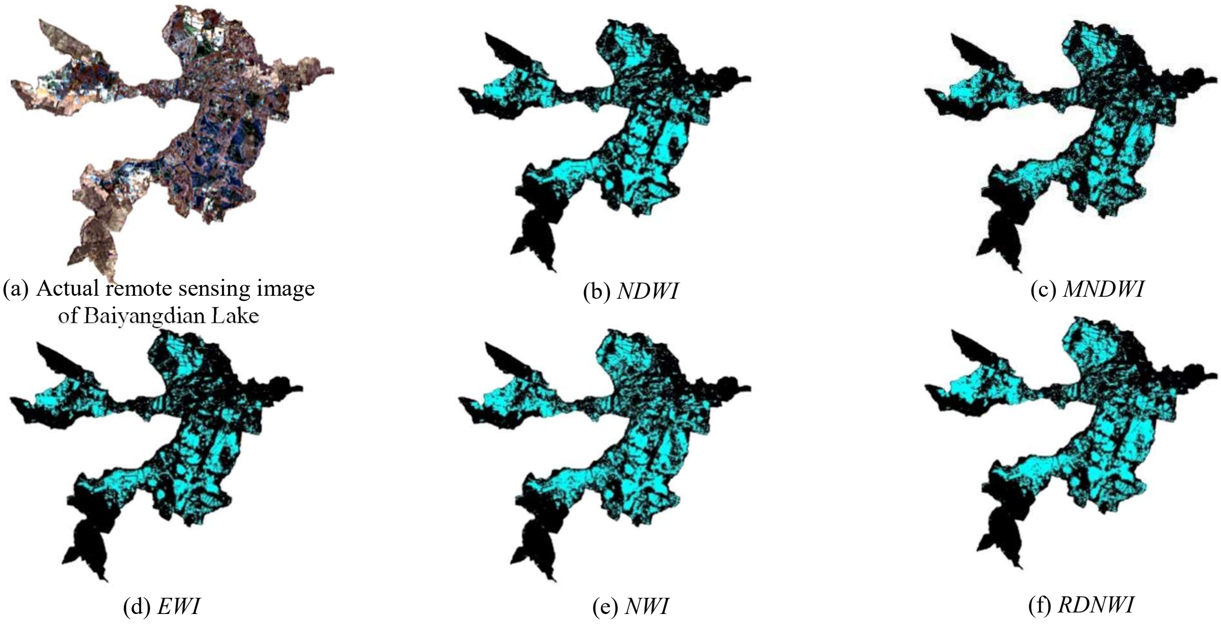

Fig. 1 Extraction results of water bodies by water body index in 2019

Table 2. Evaluation of the extraction accuracy of each water index in 2019

Water index model	Overall classification accuracy (%)	Kappa coefficient	Drawing accuracy (%)	User accuracy (%)	Mismarking error (%)	Leakage error (%)
NDWI	95.47	0.902	96.12	96.84	3.16	3.88
MNDWI	87.73	0.723	88.18	93.34	6.66	11.82
EWI	91.97	0.822	91.27	96.70	3.30	8.73
NWI	85.46	0.685	88.83	88.39	11.61	11.17
RNDWI	88.20	0.749	93.08	88.11	11.89	6.92

4. Results and Analysis

Water bodies were extracted using *NDWI* for each year from 2003 to 2023. The extracted water bodies were binarized, converted to vector maps, and combined with corresponding remote sensing images to remove non-water fragments and isolated water bodies. The resulting vector distribution maps were overlaid year by year to create a water area change map (Figure 2).

As can be seen from Figure 2, the water area of Baiyangdian Lake is generally in an expanding trend from 2003 to 2023, especially in the cultivated land in the northwest and southwest, which may be related to the decrease of agricultural and industrial activities around it. In order to analyze the variation rule of Baiyangdian water area more intuitively from the charts and data, the change rate of the water area is calculated based on the statistics of the water area of Baiyangdian in each year [17]. The calculation formula is as follows:

$$R = \frac{A_{later} - A_{earlier}}{A_{earlier} \times Y} \tag{1}$$

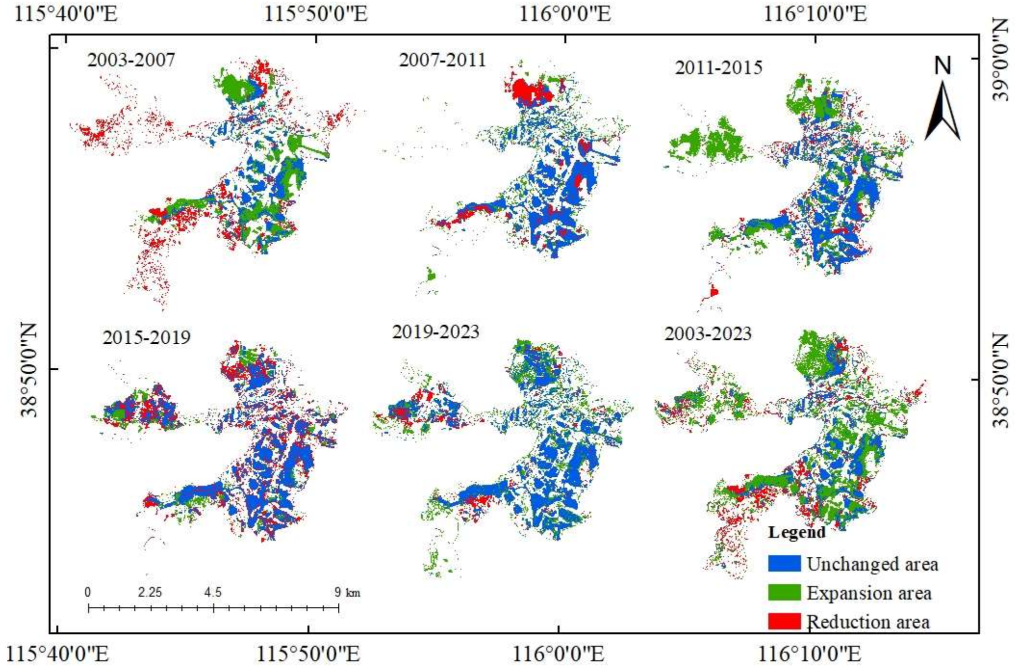

Fig. 2 Changes in the water area of Baiyangdian Lake from 2003 to 2023

In formula (1), R represents the change rate of the water area of the study area, $A_{earlier}$ represents the water area of the previous year of the study area, A_{later} represents the water area of the year after the study area, and Y represents the time interval of adjacent years. In the results, if R>0, it indicates that the water area of the study area is expanding, and the larger the value, the faster the expansion speed. If R<0, it indicates that the water area of the study area is shrinking, and the smaller the value, the faster the shrinking speed. The statistical results are shown in Table 3.

Table 3. Changes in the water area of Baiyangdian Lake from 2003 to 2023

Year	Water Area (km^2)	Change Area (km^2)	Area Change Rate (%)
2003	71.009	----	----
2007	87.075	16.066	5.656
2011	86.887	-0.188	-0.054
2015	117.931	31.044	8.932
2019	95.119	-22.812	-4.836
2023	124.232	29.113	7.652

5. Conclusion

This study used Landsat TM and OLI images from 2003 to 2023 during Baiyangdian's flood season, applied five water indices (*NDWI, MNDWI, EWI, NWI, RNDWI*) to extract water bodies, and assessed their accuracy using a confusion matrix. *NDWI* was found to have the highest accuracy, lowest errors, and was most suitable for Baiyangdian. Using *NDWI*, water bodies were extracted for each year, and water area changes were analyzed. The conclusions are:

(1) Among the five water indices, *NDWI* had the highest overall accuracy, *Kappa* coefficient, mapping accuracy, and user accuracy, with the lowest commission and omission errors. Therefore, *NDWI* was the most suitable water index for water body extraction in Baiyangdian.

(2) From 2003 to 2023, Baiyangdian's water area expanded overall from 71.009 km^2 to 124.232 km^2, an increase of 53.223 km^2 with a change rate of 18.738%. The maximum increase occurred between 2011 and 2015. Spatially, the central water area remained stable with slight expansion, while the northwest and southwest agricultural areas showed fluctuating but overall expanding water areas, indicating gradual ecological improvement.

Acknowledgments

National Innovative Training Project for College Students: Ecological Environment Assessment of Baiyangdian Wetland based on Remote Sensing in the context of carbon Neutrality (No. 202410081068).

References

[1] ZHANG Wen, JIA Yilin, CUI Changlu, et al. Analysis of Water Area Changes in Baiyangdian Based on Multi-source Data[J]. Water Resources Information Technology, 2017, (05): 39-45.

[2] LI Miao, ZHOU Jialiang, YANG Wei, et al. Changes in Water Space Pattern and Maintenance Mechanism in Baiyangdian Basin[J]. Geographical Science, 2024, 44(06): 1102-1110.

[3] ZHAO Zikun, TIAN Yu, et al. Spatial and Temporal Variation Characteristics of Surface Water Area in the Yellow River Basin from 1986 to 2021[J]. Journal of Applied Ecology, 2023, 34(03): 761-769.

[4] ZHANG Qing, FENG Zhimin, CHEN Peng. Comparison of Glacier Lake Water Body Extraction Methods Using GF-1 Remote Sensing Images[J]. Surveying and Spatial Geographic Information, 2021, 44(01): 17-19+24.

[5] LI Xinyue, ZHANG Jin, JIA Xiaoyi, et al. Comparison and Analysis of Water Body Extraction Methods for Urban Floods[J]. Groundwater, 2020, 42(05): 179-183.

[6] FU Baoqing, FU Jian, CAO Hua, et al. Dynamic Analysis of Large Lake Area Changes in Jiujiang City Based on Landsat Images[J]. Jiangxi Science, 2024, 42(04): 768-775+833.

[7] QIU Huang'ao, CHENG Pengen, GAN Tianhong. Comparative Study on Automatic Water Body Extraction Methods from Multi-spectral Images[J]. Yangtze River, 2017, 48(24): 111-116.

[8] ZHOU Han, YE Huping, WEI Xianhu, et al. Comparative Study on Water Body Extraction Methods Based on Sentinel-1/2-A Case Study of Small Water Bodies in Sri Lanka[J]. Journal of the University of Chinese Academy of Sciences, 2019, 36(06): 794-802.

[9] ZHU Jinfeng, ZHOU Yi, WANG Shixin, et al. Evaluation of Wetland Ecological Functions and Zoning in Baiyangdian[J]. Acta Ecologica Sinica, 2020, 40(02): 459-472.

[10] YANG Wei, SUN Lixin, WANG Xuan, et al. Evolution Trend of Ecosystem Services in Baiyangdian Driven by Ecological Water Replenishment[J]. Journal of Agro-Environment Science, 2020, 39(05): 1077-1084.

[11] McFEETERS S K. The use of the normalized difference water index (NDWI) in the delineation of open water features[J]. International Journal of Remote Sensing, 1996, 17(7): 1425-1432.

[12] XU Hanqiu. Study on Water Body Information Extraction Using the Modified Normalized Difference Water Index (MNDWI)[J]. Journal of Remote Sensing, 2005, (05): 589-595.

[13] YAN Pei, ZHANG Youjing, ZHANG Yuan. Study on Extraction of Water System Information in Semi-arid Areas Using Enhanced Water Index (EWI) and GIS Noise Reduction Technology[J]. Remote Sensing Information, 2007, (06): 62-67.

[14] DING Feng. Experimental Study on Water Body Information Extraction Using New Water Index (NWI)[J]. Surveying Science, 2009, 34(04): 155-157.

[15] BOHAN Y, XINLI K. Analysis on Urban Lake Change During Rapid Urbanization Using a Synergistic Approach: A Case Study of Wuhan, China[J]. Physics and Chemistry of the Earth, 2015, 89-90: 127-135.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202505_11(5).0007

[16] ZHANG Qiman, YANG Jingtai. Extraction and Dynamic Change of Lakes in the Naqu Region of the Tibet Autonomous Region[J]. Bulletin of Surveying and Mapping, 2023, (S1): 92-97.

[17] HAN Wei, XU Shan. Characteristics of Land Use Change and Research on Ecosystem Service Value in Songnen Plain-A Case Study of Harbin City[J]. Chinese Agricultural Bulletin, 2022, 38(26): 82-90.