Research on Baiyangdian Lake Water Body Changes and Water Quality Parameters Inversion Based on Landsat Dense Time Series Data

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Abstract: Baiyangdian Lake is the largest wetland ecosystem in North China, which has a special strategic position, so it is of great significance to study its temporal and spatial changes. Based on the 112 Landsat satellite remote sensing data from 1984 to 2020, this paper extracted the thematic information of Baiyangdian Lake open water body, carried out the study on the temporal and spatial evolution of the Baiyangdian Wetland ecosystem, and analyzed its area change trend as "increase-decrease-increase-decrease again-increase again". Among them, the Landsat7 ETM SLC-off satellite digital product with band noise during 2003-2012 was repaired, so that it can better reflect the mutation characteristics and overall laws of Baiyangdian Lake water body in the past 30 years. On this basis, the Baiyangdian Lake water quality parameters were inverted, and the conclusions drawn have certain reference significance for maintaining the ecological environment of Baiyangdian Lake.

1. Introduction
Baiyangdian Lake is the largest and most typical freshwater lake wetland in the North China Plain, which plays an important role in maintaining biodiversity, regulating regional climate, supplementing groundwater, and protecting biodiversity[1-2]. It has significant functions such as flood storage, drought prevention, erosion control, siltation promotion, land creation, pollution reduction, and carbon sequestration, which is called the "Kidney of North China". Therefore, it is of great practical significance to strictly protect the Baiyangdian Wetland.

For a long time, under the combined effects of human activities and climate change, Baiyangdian Wetland has suffered from crises such as insufficient water sources, sedimentation, frequent dry deposits, wetland shrinking, and biodiversity reduction[3-6]. In recent years, more and more scholars have begun to study the dynamic changes of Baiyangdian Lake's landscape pattern, however, the remote sensing data selected for these studies have a large interval between time nodes[7-10], there is a long period of time missing due to the instrument malfunction of the Landsat7 satellite[11], the data source is not uniform[12], and the time scale of these data has not yet covered the past five years, making it impossible to accurately know the temporal and spatial characteristics of Baiyangdian Wetland in past decades. This study intends to repair the missing image data caused by the instrument malfunction of Landsat satellites, increase the density of image usage in historical periods, and achieve continuous observations of the Baiyangdian Lake water body based on Landsat from 1984 to 2020, and further invert the water quality changes of the Baiyangdian Wetland, which provides quantitative data support for the protection and
management of the Baiyangdian Wetland and the ecological environment protection of Xiong’an New Area.

2. Study Area & Data

2.1. Overview of the study area
Baiyangdian Lake is located in the middle of North China Plain of Hebei Province, between 115°38′ ~ 116°07′ east longitude and 38°43′ ~ 39°02′ north latitude. The total area of Baiyangdian Lake is 366km², with a length of 39.5km from east to west, and a width of 28.5km from north to south, which terrain is higher in the west and lower in the east, and belongs to the Daqing River system of the Haihe River Basin. Baiyangdian Lake watershed is located in the eastern part of the basin, which mainly receives water from the north, south and middle rivers of the basin. The main rivers include Juma River, Tang River, Zhulong River, Bao River and Cao River. The Baiyangdian Lake Basin has a temperate semi-arid continental monsoon climate, 70% to 80% of the rainfall is concentrated in June to September, mostly torrential rains. Most of the rainfall distributes on the windward slopes of the western mountainous areas, and less rainfall on the back of the mountainous areas and plains. Baiyangdian Lake has 143 lakes and more than 3,700 trenches, forming a special landform with lakes in the lake, connected by the trenches, and garden fields and water surfaces alternately distributed.

Table 1. Summary of water bodies extraction data in Baiyangdian Lake area

| Satellite Digital Products | Selected time          |
|---------------------------|------------------------|
| Landsat5 TM               | 1984-08-16, 1984-12-06, 1985-07-18, 1986-01-01, 1986-03-15, 1987-07-24, 1987-09-10, 1987-12-15, 1988-02-01, 1988-10-14, 1989-03-07, 1989-06-27, 1989-10-17, 1990-01-05, 1990-10-20, 1991-06-17, 1991-11-08, 1992-05-18, 1992-06-19, 1992-09-07, 1992-12-28, 1993-03-02, 1993-06-22, 1993-08-25, 1993-12-31, 1994-06-09, 1994-09-13, 1994-12-02, 1995-04-09, 1995-06-28, 1995-09-16, 1996-03-26, 1996-05-29, 1996-12-23 |
| Landsat7 ETM SLC-on       | 1999-07-01, 1999-08-02, 1999-12-24, 2000-04-30, 2000-05-16, 2000-08-20, 2000-12-10, 2001-07-06, 2001-11-11, 2002-03-19, 2002-05-22, 2002-06-07, 2002-07-09, 2002-10-13, 2002-10-29, 2002-11-14, 2002-11-30, 2003-05-25 |
| Landsat7 ETM SLC-off      | 2003-08-13, 2003-10-16, 2003-12-19, 2004-01-04, 2004-01-20, 2004-04-09, 2004-08-31, 2004-12-05, 2005-03-11, 2005-06-15, 2005-09-03, 2005-12-08, 2006-03-14, 2006-04-15, 2006-07-04, 2006-11-09, 2007-03-17, 2007-06-05, 2007-09-09, 2007-12-30, 2008-02-16, 2008-05-06, 2008-09-11, 2008-12-16, 2009-03-06, 2009-06-10, 2009-08-13, 2009-12-19, 2010-02-21, 2010-05-12, 2010-08-16, 2010-11-20, 2011-01-23, 2011-05-15, 2011-09-20, 2011-12-09, 2012-02-11, 2012-03-14, 2012-05-17, 2012-10-24 |
| Landsat8 OLI_TIRS         | 2013-05-12, 2013-09-01, 2013-11-20, 2014-04-29, 2014-08-19, 2014-10-06, 2015-03-15, 2015-05-18, 2015-09-07, 2015-10-09, 2016-04-18, 2016-12-14, 2017-04-21, 2017-07-10, 2017-09-28, 2017-12-01, 2018-12-04, 2019-09-02, 2020-04-13, 2020-09-20 |

2.2. Time series data source
In this study, various sensor data from the American Earth Resources Satellite Landsat from 1984 to 2020 were selected as the data source for remote sensing monitoring of water body area in Baiyangdian Lake area. Based on the monitoring frequency of 1 time per season and 4 times per year and the specific image quality status of the Baiyangdian Lake area in each scene image, 112 scenes of satellite images with better data quality were selected with a total of 112 periods (Table 1).
3. Methods

3.1. Data preprocessing
Using ENVI software to perform preprocessing procedures such as radiometric calibration, atmospheric and orthorectification, and target area clipping on remote sensing data from 1984-2002 and 2013-2020, to convert the DN value of the original image pixel into the surface reflectance.

On May 31, 2003, the Landsat7 ETM+ airborne scan line corrector (SLC) malfunctioned, resulting in the loss of data bands in the Landsat7 ETM SLC-off satellite digital products acquired thereafter, which seriously affected the use of remote sensing images at this stage. Therefore, for the remote sensing data from 2003 to 2012, the ENVI plug-in Landsat_gapfill was used to repair it. The repair effect is shown in Figure 1. The subsequent preprocessing procedures such as radiometric calibration were carried out.

![Comparison before and after data restoration on August 13, 2003](image)

3.2. Water extraction
Aiming at the spectral characteristics of water bodies on multispectral remote sensing data, this paper used the improved normalized difference water index MNDWI (Modified NDWI) [13] to extract Baiyangdian Lake water bodies. MNDWI was obtained by modifying the band combination of the Normalized Differential Water Index (NDWI), which is one of the most typical and widely used water extraction methods. MNDWI has a wider range of applications than the NDWI index. It can detect subtle changes in water bodies and eliminate the influence of topographical differences, which is widely used in the accurate extraction of water body information within vegetation areas and cities and towns [13-14]. The formula is shown as below:

\[ \text{MNDWI} = \frac{\text{Green} - \text{MIR}}{\text{Green} + \text{MIR}} \]  

Among them, Green represents the surface reflectance in the green light band, such as the 2 band of the TM/ETM+ image and the 3 band of the OLI image. MIR is the surface reflectance in the mid-infrared band, such as the 5-band of TM/ETM + and the 6-band of OLI images.

Firstly, the MNDWI value of each image was calculated, and then the water segmentation threshold was calculated according to its histogram characteristics, and the water part was initially extracted according to the threshold. On this basis, Baiyangdian Lake's existing water body distribution data was used to eliminate other interference information, and the final extraction result was calculated for the water land area.

3.3. Inversion of water quality parameters
Dissolved oxygen (DO) is the basis for studying the self-purification ability of water, and it is one of the main evaluation indicators for the classification of urban black and odorous water bodies. The formula for constructing the inversion model is as follows:
DO = 20.888*(Green - Red)/(Green + Red) + 8.1949                                   (2)

Among them, Green represents the surface reflectance in the green light band, such as the 2 band of the TM/ETM+ image and the 3 band of the OLI image. Red is the surface reflectance in the red light band, such as the 3 band of the TM/ETM+ image and the 4 band of the OLI image.

The oxidation-reduction potential (ORP) is one of the main evaluation indicators for the classification of urban black and odorous water bodies. The formula for constructing the inversion model is as follows:

\[ \text{ORP} = -0.216 \times \text{Blue} + 147.62 \]                                                     (3)

In the formula, Blue represents the surface reflectance in the blue light band, such as band 1 for TM/ETM+ images and band 2 for OLI images.

The chlorophyll concentration (CHA) in water is an indicator of the distribution of plankton, and is the most basic indicator to measure the primary productivity (aquatic plant biomass) and eutrophication of the water body. The formula for constructing the inversion model is as follows:

\[ \text{CHA} = 0.4 \times \text{NIR} + 5.7482 \]                                                        (4)

Among them, NIR stands for the surface reflectance in near-infrared band, such as 4 band for TM/ETM+ images and 5 band for OLI images.

Based on the extracted water bodies, the Band Math tool in ENVI was used to calculate the DO, ORP, and CHA values of each image to realize the inversion of Baiyangdian Lake water quality parameters.

4. Results & Discussion

4.1. Water body change characteristics of Baiyangdian Wetland

Through the extraction of the open water surface of Baiyangdian Lake remote sensing images over the years (1984-2020) (part of the extraction results are shown in Figure 2 and the curve of water area change over the years is shown in Figure 3), it is found that the water area of Baiyangdian Lake has fluctuated greatly in the past 37 years. The overall trend was "increase-decrease-increase-decrease again-increase again", and the water area decreased significantly during 1984-1988, 1994, and 2001-2003. According to the records of the Shifangyuan Hydrological Observation Station of Baiyangdian Lake from 1919 to 2005, taking the 6.5m water level of Shifangyuan as the standard for Baiyangdian Lake dry lake, the years that dry lakes appear during the year or throughout the year include 1 year in the 1920s (1922) and 1 year in the 1960s (1966), 4 years in the 1970s (1971-1973, 1976), 8 years in the 1980s (1981-1988), 1 year in the 1990s (1994), and again in 2001, 2002 and 2003. The remote sensing inversion results are consistent with these hydrological site records.

Previous studies on water body changes in Baiyangdian Wetland are mostly based on remote sensing images selected at a time interval of 5-10 years, which can only reflect the general evolution trend, and it is impossible to know the evolution characteristics of the water body in Baiyangdian Wetland in detail on a time scale. This paper selects remote sensing images according to the monitoring frequency of 1 time per season and 4 times per year, repaired 41 periods of data with band noise, and used 112 periods of data to participate in the analysis of water bodies changes in Baiyangdian Wetland, which effectively compensates for the inadequacy of the low density of the previous image data. In years with sudden changes in precipitation or large artificial disturbances, such as 1988, 1992, 1998, 2004, 2006 [1,15], a complete time series study also can better reflect the characteristics of Baiyangdian Lake water body change.
Figure 2. Extraction results of some water bodies in Baiyangdian Lake area

Figure 3. The change curve of water body area in Baiyangdian Lake over the years
4.2. Inversion analysis of Baiyangdian Lake water quality parameters

Analyzing the inversion results of Baiyangdian Lake water quality parameters from 1984 to 2020 shows that the water quality of Baiyangdian Lake is mainly non-pollution - light pollution. From the inversion of dissolved oxygen and redox potential (Figure 4), most of the areas are non-pollution, and a few areas with frequent human activities are light-to-moderate pollution. From the inverted chlorophyll concentration (Figure 5), because of the various submerged and emergent plants growing in Baiyangdian Lake, the chlorophyll concentration of Baiyangdian Lake presents light-to-moderate pollution. Due to the frequent ecological replenishment of Baiyangdian Lake in recent years, the water quality distribution of the entire Baiyangdian Lake also shows a different distribution throughout the year.

![Figure 4. Baiyangdian Lake dissolved oxygen (DO) and redox potential (ORP) concentration inversion diagram](image)

![Figure 5. The inversion diagram of the chlorophyll (CHA) concentration of Baiyangdian Lake](image)

5. Conclusions

In this study, the 112 Landsat satellite data was used to extract the thematic information of Baiyangdian Lake water body from 1984 to 2020, and carry out the research on the temporal and spatial evolution of the Baiyangdian Wetland ecosystem, the trend of its area change is "increase-decrease-increase-decrease again-increase again". The restoration of the data with band noise from 2003 to 2012 improves the accuracy and reliability of the research results, so that it can better reflect the mutation characteristics and overall laws of the Baiyangdian Lake water body in the past 30 years. On this basis, the Baiyangdian Lake water quality parameters were inverted, and the conclusions drawn have certain reference significance for maintaining the ecological environment of Baiyangdian Lake.
Based on the research in this paper and combined with the historical period of temperature, rainfall and other hydrological big data, our future research will explore the more fine-grained change characteristics of the Baiyangdian Lake, and deeply study the variation characteristics of Baiyangdian Wetland water quality parameters in the time domain.

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