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Research Article

Blue-Green Space Changes of Baiyangdian Wetland in Xiong'an New Area, China

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As a regulator of ecological environment, Baiyangdian Wetland is in a pivotal position in constructing the blue-green space (BGS) of Xiong'an New Area in China. This study aims to reveal the spatiotemporal changes of the BGS in Baiyangdian Wetland from 2016 to 2021. It uses Google Earth Engine (GEE) to calculate NDVI and NDWI based on Sentinel-2 Satellite remote sensing data and extracts the blue-green space by a classification model driven by NDVI and NDWI. Moreover, the land-use transfer matrix and landscape pattern indices are applied for evaluating the BGS changes in the wetland. According to the results, vegetation in the wetland shows no obvious spatial transfer. From 2016 to 2020, the BGS proportion in the wetland showed a stable increase, with the blue space getting larger by 10.8%. The indicators of the Number of Patches (NP), Patch Density (PD), Largest Patch Index (LPI), Contagion, and Landscape Shape Index (LSI) of the wetland decreased, suggesting a better ecological environment since the establishment of Xiong'an New Area in 2017. Based on the results, the author makes the following conclusion: the construction of BGS in Baiyangdian Wetland results in a well-organized ecological environment. The study provides a reference for building Xiong'an New Area and monitoring BGS changes in other regions.

1. Introduction

Blue-green space (BGS) refers to the blue space and green space in an area. Blue space refers to the distribution of both natural and artificial water bodies in the area. Green space refers to areas that are covered by vegetation [1]. The blue-green space serves as a source of oxygen and a carbon sink in the ecological cycle. It regulates local climate and improves local environment. The enhancement of the blue-green space surrounding the urban area could effectively reduce urban heat island effects and improve air quality, benefiting the residential environment [2–6].

Xiong'an New Area, south of Beijing, was established in 2017 as a national new area and part of the millennium plan. This project is of major national significance and is a model and touchstone for high-quality development across China. The success of Xiong'an New Area marks that China is moving toward a cleaner and greener development path. For Xiong'an, "ecological and green development" is a high priority. Baiyangdian is the core water area of Xiong'an New Area, also known as the "kidney of North China". It is the largest natural freshwater lake in the North China Plain. The ecological environment of Baiyangdian is vital to the strategy of building a blue and green ecological city in the Xiong'an new area. To make the proportion of blue-green space stand at 70% of the Xiong'an New Area by 2035, a detailed study needs to be carried out on the Baiyangdian Wetland and the ecological environment changes in Xiong'an New Area.

Wetland landscape patterns and their changes directly affect the biogeochemical cycle, hydrological cycle, ecosystem services, and biodiversity protection. They have a profound impact on the blue-green spatial distribution of the wetland [7–10]. Since the 1970s, many researchers on wetlands have used landscape ecology to study the wetland pattern in different regions. The dynamic change of wetland landscape patterns has become the focus of wetland research [11–14]. Based on this, numerous academics have studied and analyzed the landscape of Baiyangdian Wetland, paying particular attention to its distinctive landscape structure, function, and pattern distribution [15–20]. For example, Yang et al. analyzed the landscapes' spatial and temporal changes in Baiyangdian Wetland and the driving factors. Moreover, they discussed future changes in the landscapes based on relevant planning [15] and their influences. Tang et al. studied the trend of aquatic plant area and biomass changes in Baiyangdian Wetland during different periods [16]. Wu et al. analyzed the dynamic changes in the water level of Baiyangdian Wetland with deep learning. Their study improved the accuracy of water-level monitoring [17]. By extracting the information of Baiyangdian Wetland with Normalized Difference Water Index (NDWI), Lin et al. studied the relationship between wetland area and the water level [18]. Zhao et al. studied the relationship between the precipitation and the lowest water level of Baiyangdian Lake and established a water-level prediction model [19, 20]. Previous studies mainly focused on the impact of the water environment on Baiyangdian Wetland. Their study directions included water quantity, water quality, wetland degradation, and ecosystem services. Nevertheless, Xiong'an New Area is built on blue water and green trees with the lake integrating with the city. The BGS changes in water and vegetation in Baiyangdian Wetland are the most urgent problem to be solved and are important to the development of the Xiong'an New Area.

Generally, research on long-time series changes with satellite remote sensing images requires massive data and complex computing. Data preprocessing is a time-consuming and laborious task. Google Earth Engine (GEE), a cloud computing data analysis platform, provides a solution. This paper has adopted GEE to analyze the Sentinel-2 Satellite remote sensing images of Baiyangdian Wetland. The images are from June to August of 2016~2021 with a 10-meter spatial resolution. The algorithm of NDVI-NDWI decision trees is used to extract information about the Baiyangdian Wetland. The results are analyzed to evaluate changes in BGS and types of Baiyangdian Wetland. In this way, the data on BGS changes in Baiyangdian Wetland before (2016) and after (2017) the establishment of Xiong'an New Area can be obtained. The data will provide technical support for the ecological protection and restoration of Baiyangdian Wetland.

2. Material and Methods

2.1. Overview of the Study Area. Baiyangdian, the largest freshwater lake in northern China, is located in the south branch of Daqing River (Figure 1). Belonging to the Haihe River Basin, it is at the center of Hebei Province and the Beijing-Tianjin-Hebei region. The wetland brings together 143 lakes of different sizes, such as Baiyangdian Lake, Zaozha Lake, Mapeng Lake, and Yaohulu Lake. Baiyangdian is rich in aquatic species such as plankton, benthic animals, and fish [16]. Baiyangdian water area effectively maintains the ecological balance of Xiong'an New Area [21]. Interweaving land with water, the wetland is also home to terrestrial plants, aquatic plants, and animals. This complex ecosystem presents a beautiful scenery of "blue water and green vegetation" in the growing season.

2.2. Data Source. GEE is jointly developed by Google, Carnegie Mellon University, and U.S. Geological Survey. This platform provides scientific analysis of geographic data based on big data and cloud computing. With high-performance computing resources, it is a good tool for processing huge amounts of geospatial data [22–24]. GEE platform contains archived remote sensing data, which is supported by NASA, U.S. Geological Survey, and NOAA, as well as PB data. The geographic information data is of different kinds and has more than 40 years of historical sequence. GEE data is updated in real-time, follows standardized storage forms, and is easy to call [25]. The remote sensing images of the study area are from the Sentinel-2 Satellite and downloaded from GEE. The data has a 10-meter spatial resolution, and its historical sequence is from June to August of 2016~2021. To discard images with many clouds and retain those with less than 20% cloud amount, this paper has developed a cloud-removing algorithm based on the bitmask information of the Sentinel-2 Satellite data. After the pixels with clouds have been eliminated in preprocessed images to the greatest extent, pure ground information is retained. NDVI data and NDWI data are derived from preprocessed images. By calculating, pixel by pixel, the average value of multitemporal data in the image stack, the average value of NDVI data, and NDWI data, both of which are from June to August of 2016~2021, can be synthesized. Finally, NDVI and NDWI results are exported from GEE for the analysis of the BGS pattern and evolution of Baiyangdian Wetland. Normalized Difference Vegetation Index (NDVI), which is a radiation quantification parameter, reflects the abundance and activity of green vegetation. Its physical basis is that vegetation chlorophyll shows strong absorption in the red-light spectrum and high reflectance in the near-infrared spectrum. Using the spectral reflectance of vegetation, the normalized difference between near-infrared and red-light spectrums can be computed in remote sensing images, namely, $NDVI = (NIR - R)/(NIR + R)$. Therefore, this study uses NDVI to inverse the green space in Baiyangdian Wetland. Normalized Differential Water Index (NDWI) is a parameter improved based on the NDVI algorithm. Its physical basis is the reflectance of vegetation and water in near-infrared and visible light spectrums. The normalized difference between near-infrared and visible light spectrums in remote sensing images is calculated based on the equation $NDWI = (Green - NIR)/(Green + NIR)$. This method inhibits the vegetation information in images and is good at distinguishing the phytoplankton on the water surface from the vegetation on the water shore. In this way, enhanced water information can be acquired. Therefore, this study uses NDWI to inverse the blue space in Baiyangdian Wetland.

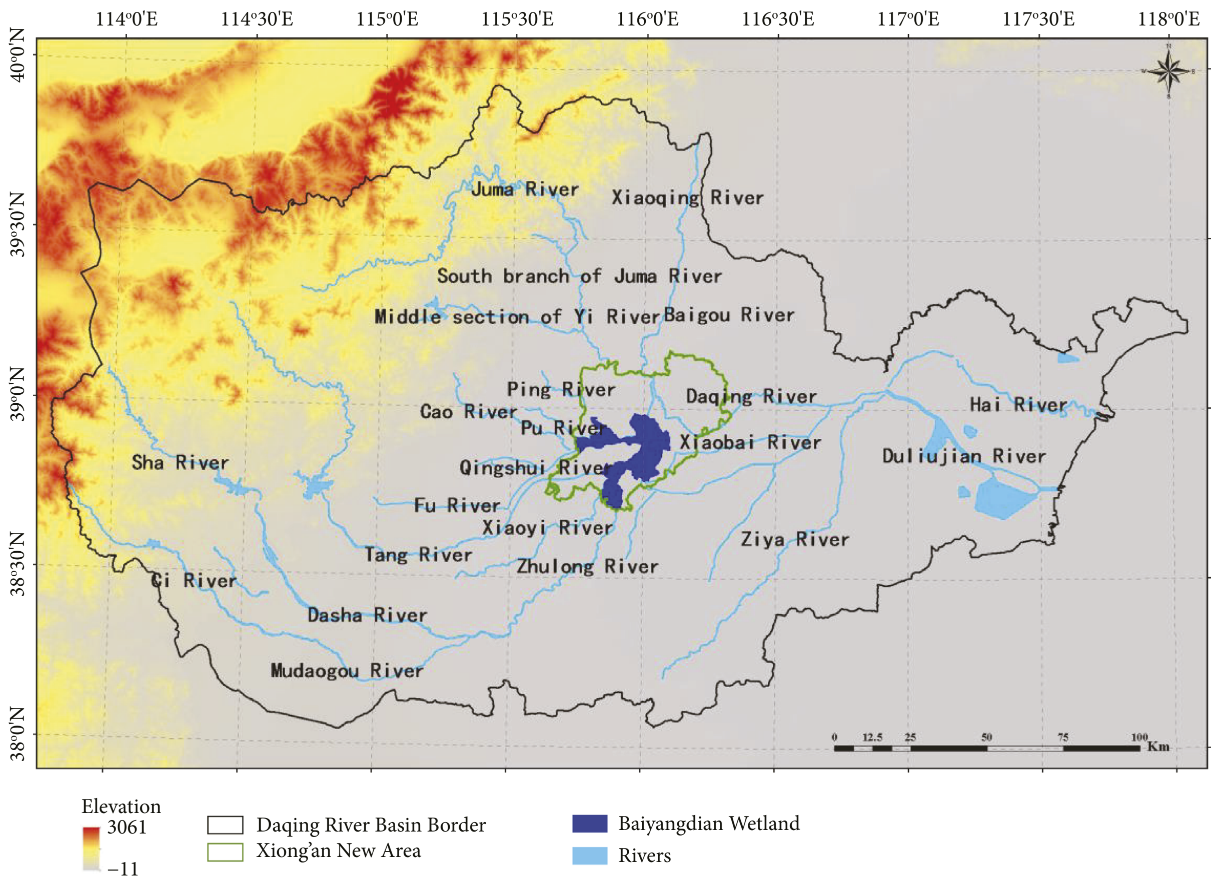

Figure 1: Overview of the study area.

Images of GF Satellite from the China Centre for Resources Satellite Data and Application (CRESDA) have higher resolution than the Sentinel-2 Satellite. GF-2 Satellite includes both 1-meter-resolution panchromatic images and 4-meter-resolution multispectral images. But GF Satellites have the coverage data for Baiyangdian Wetland from June to August, so they were not used in monitoring the BGS changes from 2016 to 2021.1-meter-resolution images of GF-2 Satellite which is "true value" are generated to only validate the remote sensing results from the Sentinel-2 Satellite which can cover all of Baiyangdian Wetland every year and it is used to obtain yearly BGS changes.

2.3. Methods

2.3.1. Wetland Classification Model. Baiyangdian Wetland has various ground objects, with closely related spectrums. For example, ground objects of the same type may show great similarity in satellite images but are different in spectrums [26]. Conventional supervised classification involves a heavy workload and is influenced by human subjectivity. Moreover, this method also needs a highly pure classification template, as well as a typical, representative, and accurate training area. It has limited application scope and is indispensable for artificial sample selection and prior knowledge of the place. In comparison, NDVI and NDWI indices are more sensitive to water and vegetation. SWIR is the short-wave infrared band channel of Sentinel-2 data, which is less scattered by the atmosphere and has a strong penetration ability. It can effectively reflect the reflection of vegetation and other ground objects and efficiently classifies waterbody, vegetation, and urban area. Therefore, as characteristics of water, urban and rural construction space and topographic shadow are easily confused, NDVI and NDWI are suitable to analyze the Baiyangdian Wetland, and the SWIR channel is utilized in this classification model to improve the accuracy of wetland ground object information. Considering the image characteristics of the study area, this paper has selected NDVI, NDWI data, and SWIR channel for analysis.

BGS information extraction model for Baiyangdian Wetland is based on the NDVI-NDWI method (Figure 2). It utilizes the changing pattern of Sentinel-2 data based on information spectrums and adopts the spectral reflectance of ground object information to categorize wetland information. The model aims to extract the results of open water, vegetation as well as urban and rural construction space. The thresholds 1-7 are the identification thresholds of NDVI and NDWI, respectively. SWIR denotes the channel reflectance of the shortwave and infrared spectrum in the Sentinel-2 data.

2.3.2. Validation of Classification Results. There are mainly two types of validation data to evaluate the results of remote

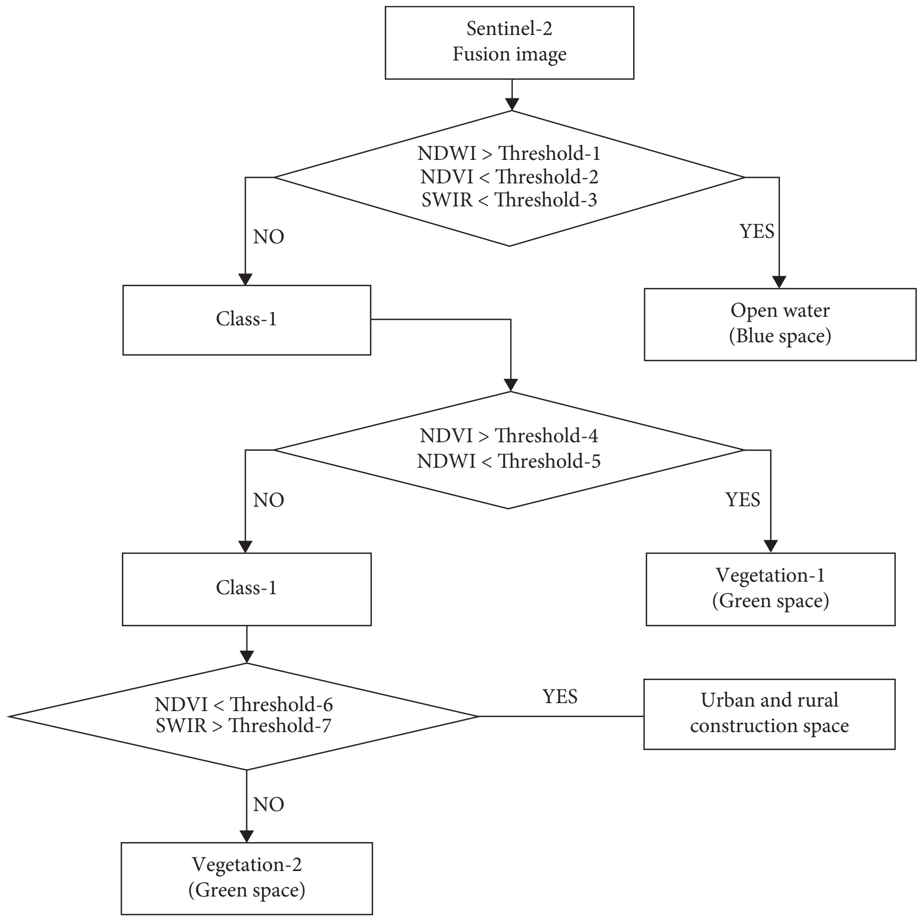

Figure 2: BGS information extraction model for Baiyangdian Wetland.

sensing classification. One is measured sampling data. The other is high-resolution satellite remote sensing data that reflects ground conditions [27]. Field investigation and sampling are difficult for some reasons. First, Baiyangdian Wetland involves a large area and various ground objects. Secondly, the wetland is often influenced by ecological flood dike, estuary wetland construction projects, and upstream floods. Third, the opening hours of Baiyangdian Wetland to the public are short. In comparison, GF-2 data has higher spatial resolution than data of Sentinel-2, GF-2, and Sentinel-2 of the same day, so it can be used during validation as the "true value" of ground. Specifically, supervised classification is used for categorizing the data before the visual interpretation for test. In this way, the classification results are extracted from GF-2 data (Figure 2). Due to the different spatial resolution of GF-2 and Sentinel-2 data, the aggregation resampling method is adopted to resample the GF-2 data into the same grid size as the Sentinel-2 data.

The classification data of 2019 from Sentinel-2 is compared with the data of the same period by GF-2 inversion (Figure 3). According to the results (Table 1), the contour of the classification data between Sentinel-2 data and GF-2 which is the "true value" is closer. The overall distribution of BGS and construction space is relatively accurate. The inversion result is the closest when extracting the open water.

The model built in Figure 2 can precisely extract data of small and scattered water areas. When extracting the transition between water and vegetation, the model's inversion result is close to the true value. In other words, the model can reflect the contour of the transition area.

To evaluate the accuracy, correlation coefficient (R), mean error (ME), and root mean square error (RMSE) are used for comparative analysis. For the statistical analysis of inversion results, 1 is set as the digital number (DN) of blue space, 2 for green space, and 3 for construction space in urban and rural areas. According to Table 1, R between the classification result and the "true value" reaches 0.948, passing the 99% significance test. Mean bias (MB), mean error (ME), and root mean square error (RMSE) are 0.06, 0.203, and 0.144, respectively. Thus, the classification results of the proposed BGS information extraction model are highly accurate.

2.3.3. Landscape Pattern Index. The landscape pattern index is a basic means to study the landscape pattern, usually from the type level scale and the landscape level scale [15]. Based on the understanding of the landscape pattern index, the indicators of patch number (NP), patch density (PD), and the contagion index (CONTAG) were selected in the ecological process to evaluate the BGS and construction space in

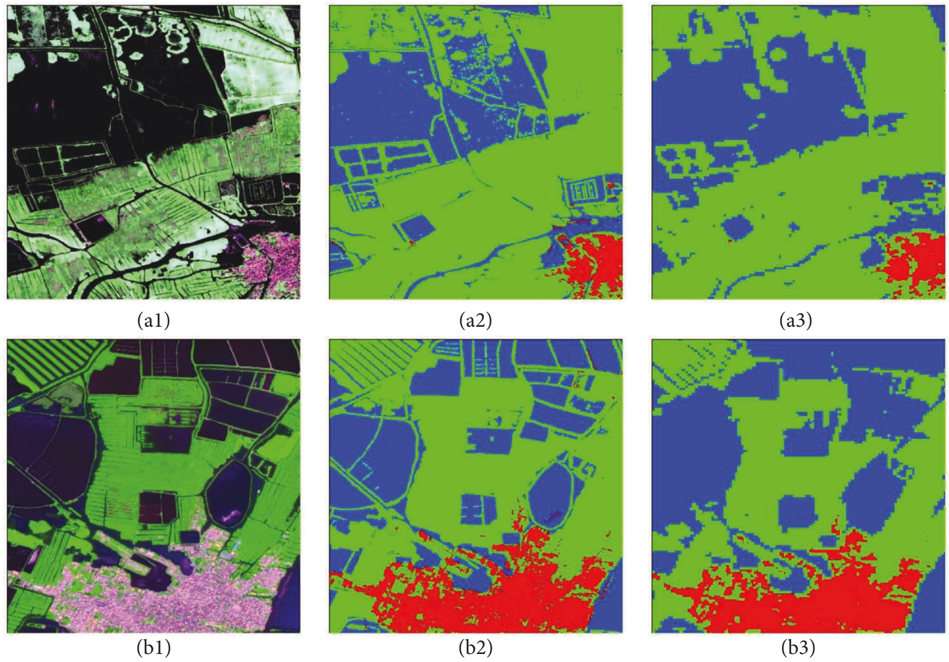

Figure 3: Comparison between Baiyangdian Wetland sample images and classification data of the model built based on GF-2 and Sentinel-2 data (a1 is region 1, a2 is the classification result of the model built based on GF-2 data in region 1, a3 is the classification result of the model built based on Sentinel-2 data in region 1, b1 is region 2, b2 is the classification result of the model built based on GF-2 data in region 2, and b3 is the classification result of the model built based on Sentinel-2 data in region 2).

Table 1: Accuracy test of the classification results of the model.

	R	P	MB	ME	RMSE
Test	0.948	0.001	0.060	0.203	0.144

Baiyangdian Wetland. These indices can reflect changes in the aggregation and fragmentation of BGS, and thus assess the ecological function of BGS. Landscape pattern indices can quantitatively describe the changing pattern of the landscape. By analyzing the relationship between landscape pattern and landscape process, we can further study the landscape structure and spatial pattern in the study area and know about the precise dynamic changes of landscape pattern in the Baiyangdian Wetland [28]. During the study of small-scale BGS, such as the BGS of wetlands, the biggest external influential factor for the structure is human activity. Fragmentation and landscape diversity are also important features [26]. Therefore, this study has calculated the spatial heterogeneity, fragmentation degree, and patch complexity of Baiyangdian Wetland landscape. It has also analyzed the dynamic changes of BGS in Baiyangdian Wetland from the horizontal orientation.

3. Results

3.1. BGS Changes of Baiyangdian Wetland. According to the classification results (Figure 4) from Sentinel-2 data, the green space is mainly concentrated in the north, the northwest, and the southwest of the wetland. The overall distribution pattern is as follows: the north has more green space than the south and the west has more green space than the east. The blue space is mainly scattered in the southeast and northeast of the wetland.

As for annual changes in Baiyangdian Wetland, the BGS proportion increased steadily from 2016 to 2020, among which the proportion of blue space increased with some fluctuations. However, in 2021, due to the construction of the ecological function area in the northwest, some green space was transformed into urban and rural construction space, resulting in a small decrease in the BGS proportion (Figure 5).

From 2016 to 2021, due to constant ecological replenishment of water, the proportion of blue space in Baiyangdian Wetland increased by 10.8%, with an area of 64.8 km^2. The proportion of green space decreased by 3.3% (Table 2), without obvious spatial transfer (still concentrated in the northern, northwestern, and southwestern regions).

3.2. Landscape Pattern Changes of Baiyangdian Wetland. In the landscape pattern analysis, higher fragmentation, which means increases in numbers of patches (NP) and patches density (PD) [29], indicates a worse ecological function of the landscape. The landscape shape index (LSI)

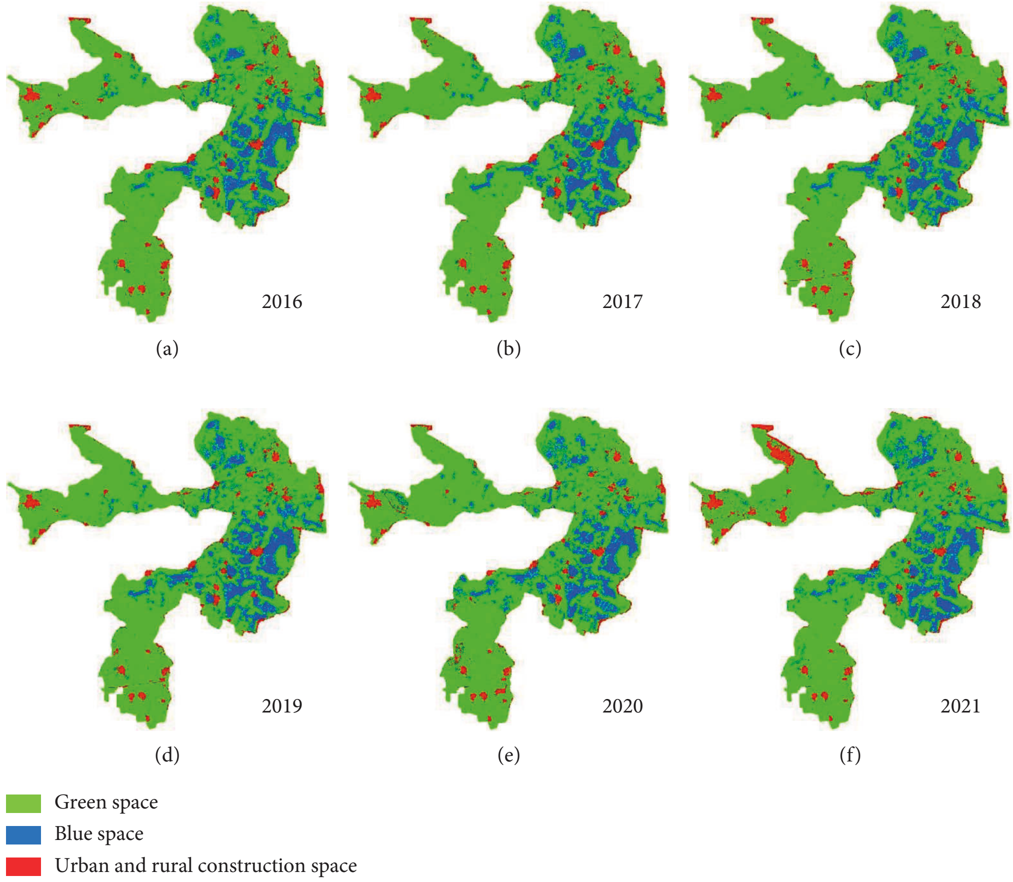

Figure 4: BGS distribution changes of Baiyangdian Wetland from 2016 to 2021. (a) 2016. (b) 2017. (c) 2018. (d) 2019. (e) 2020. (f) 2021.

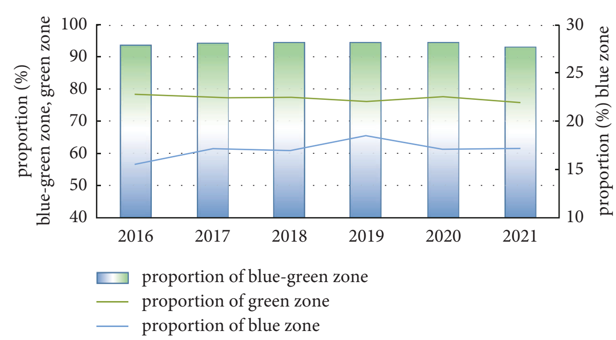

Figure 5: BGS changes of Baiyangdian Wetland from 2016 to 2021.

Table 2: Transfer matrix of BGS in Baiyangdian Wetland from 2016 to 2021 (km^2).

	Green space	Blue space	Urban and rural construction space	2016
Green space	267.61	17.54	9.74	294.90
Blue space	11.32	47.09	0.01	58.42
Urban and rural construction space	6.31	0.12	17.81	24.24
2021	285.24	64.09	27.56	-

of Baiyangdian Wetland from 2016 to 2021 is shown in Figure 6. According to the figure, NP and PD decreased from 2016 to 2021, despite some fluctuations. NP dropped from 8,904 to 7,755, and PD falls from 24.4942 to 21.3334. These results suggest lower fragmentation of Baiyangdian Wetland. LSI shows the same trend as NP and PD, indicating simpler landscape shapes and better ecological function of the landscape.

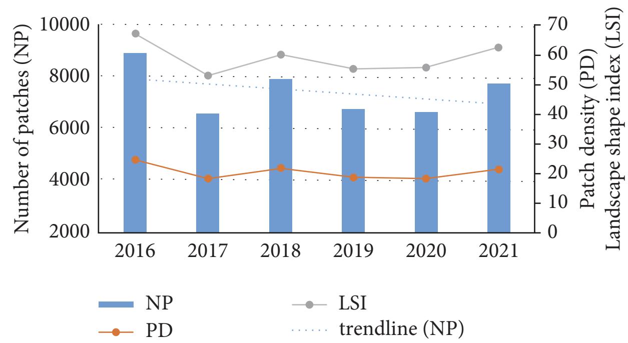

Figure 6: Changes in landscape pattern indices (NP, PB, and LSI) of Baiyangdian Wetland from 2016 to 2021.

3.3. BGS Changes of Baiyangdian Wetland. Figure 7 shows the largest patch index (LPI) of the BGS and construction space in urban and rural areas of Baiyangdian Wetland from 2016 to 2021. According to the figure, PD shows a decreasing trend. This indicates that systematic ecological management helps the landscape of Baiyangdian Wetland change from complicated and discontinuous patches to homogeneous and continuous BGS. As the fragmentation of the landscape declines, the ecosystem becomes more efficient and stable. The urban and rural construction space increased slightly in 2021 because of the enhanced ecological land.

4. Discussion

This paper provides a scientific reference for monitoring and evaluating the ecological environment of Baiyangdian Wetland and wetlands with similar features. The author finds that since the establishment of Xiong'an New Area, a well-organized and balanced wetland ecosystem has been built.

4.1. Baiyangdian Blue-Green Space Division. The concept of blue-green space (BGS) proposed in this study represents the two most significant driving factors of the ecological environment: vegetation and open water. However, different land-use classification systems will affect the results of blue-green spatial (BGS) change analysis, especially on the BGS division in wetlands. Current blue-green space research mainly analyzes urban evolution. For example, Cui Jie, Yang Liuqi, Song Shuang, et al analyzed the evolution and driving factors of street view and blue-green spatial landscape patterns of central cities in Xuzhou, Wuhan, and Northeast China [30–32]. However, their division of the blue-green space was too general, and the wetland classes were categorized as blue space, and the aquatic vegetation in the wetland was not separated. This limitation leads to the deviation of the division of the blue-green space. In their research on Baiyangdian Wetland, Zhu Jinfeng and Liu Chunlan divided the paddy field, reed field, and lotus pond into vegetation classes [33, 34]. Based on the definition of wetlands and the classification in Baiyangdian Wetland, this paper suggests that paddy fields and aquatic vegetation should be regarded as important components of green space. The blue space in the Baiyangdian Wetlands specifically refers to the water body, which contains open water lakes, wide waterways, ditches, and fishponds. The green space in wetland includes aquatic plants, terrestrial plants, cultivated land, and forest land.

4.2. Reasons for the Change of Blue-Green Space in Baiyangdian. Nevertheless, by the end of the study period, the wetland ecological restoration project was still under construction. As a result, there was a slight decrease in the proportion of BGS in the satellite images of Baiyangdian. A part of the green space in northwest Baiyangdian Wetland was converted into urban and rural construction space. To restore the ecology of the wetland area, a project of returning farmland to water body has been carried out in Pinghe River. Thus, the pattern of the wetland area changes, and the green space transferring to construction space is partial and temporal.

Since the establishment of Xiong'an New Area, ecological water replenishment has been implemented multiple times. The construction of ecological treatment projects and restoration will help change local blue-green spatial distribution in the future.

The BGS changes of Baiyangdian Wetland are greatly affected by weather and climate. Future studies could consider the influence of weather and climate on the BGS changes. Meanwhile, how human factors change the BGS of Baiyangdian Wetland should also be studied. The factors include economic development, water diversion, and water replenishment.

4.3. Advantages and Disadvantages of Classification Methods. Many researchers have used 30-meter resolution Landsat satellite data to classify wetland landscape patterns in long-term series to study the dynamic changes [35–38]. However, such a method has limited classification accuracy due to the medium-resolution Landsat images. To more efficiently divide the landscape of the Baiyangdian wetland into detailed categories, the decision tree method of NDVI-NDWI-SWIR has been created by a 10-meter resolution Sentinel-2 satellite. The results of validation with 0.8-meter resolution Gaofen-2 satellite data show that the classification accuracy is high. Compared with prior studies, this study focuses on the period after the establishment of the Xiong'an New Area. It adopts targeted measures to show the changes in Baiyangdian during its transformation into an ecological-

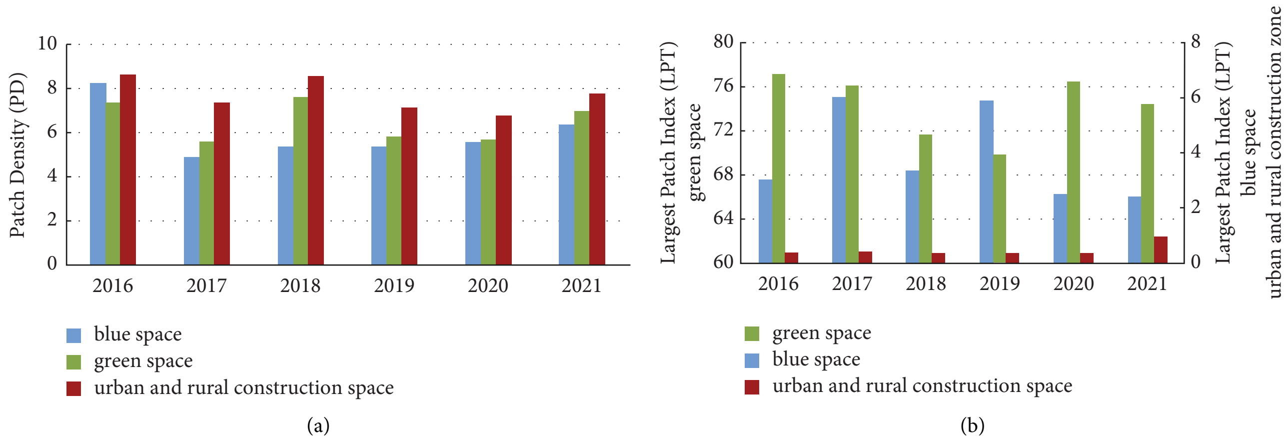

Figure 7: Patch properties of BGS and construction space in urban and rural areas of Baiyangdian Wetland from 2016 to 2021.

friendly city. The results of this study could provide practical references for the planning and management of Baiyangdian Wetland. However, as the Xiong'an New Area was established in recent years, most of the analyses are based on limited historical series data. There are still limitations to overcome in the analysis of landscape patterns. During the ecological restoration of the Baiyangdian Wetland and the construction of the Xiong'an New Area, further studies need to be carried out on the spatial distribution of blue-green space, the optimization of regional landscape patterns, and the construction of ecological patterns in the Xiong'an New Area. With the development of multisource remote sensing technology, more high-resolution data can be selected for the blue-green space inversion to improve classification accuracy.

5. Conclusion

Baiyangdian Wetland has become the core area of Xiong'an New Area since 2016. Based on the model of extracting the BGS information and calculation of landscape pattern indices, this paper has analyzed the spatiotemporal changes of the BGS in the Baiyangdian Wetland. The analysis shows that:

(1) The correlation coefficient between the classification result of Sentinel-2 in the 10-meter resolution and validation data of GF-2 in the 1-meter resolution is as high as 0.948, passing the 99% significance test. The MB, ME, and RMSE are 0.06, 0.203, and 0.144, respectively. The model applied in this study area has high accuracy and meets the demand of spatial analysis. Therefore, this model can be used for obtaining the detailed BGS and landscape changes in Baiyangdian Wetland from Sentinel-2 data.

(2) There is no obvious spatial transfer of vegetation in Baiyangdian Wetland from 2016 to 2021. Most green space concentrates in the north, the northwest, and the southwest of the wetland. The blue space is scattered in the southeast and the northeast of the wetland.

(3) From 2016 to 2021, NP, PD, LPI, and LSI of Baiyangdian Wetland all decreased, indicating a better ecological environment and more stable ecosystem of Baiyangdian Wetland since the establishment of Xiong'an New Area in 2017.

(4) The BGS proportion in Baiyangdian Wetland increased steadily from 2016 to 2020, among which the proportion of blue space increased by 10.8%. However, 2021 witnessed a slight decrease in BGS and a minor increase in the construction space in urban and rural areas. This was the result of the ecological construction. Baiyangdian Wetland ecology restoration project is still under construction. Its progress and changes will be monitored continuously.

Data Availability

The data that support the findings of this study are available upon reasonable request from the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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