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The Spatial and Temporal Variability of the Blue–Green Spatial Structures of the South Dongting Lake Wetland Areas Amidst Climate Change, including Its Relationship with Meteorological Factors

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Abstract: In recent years, the water level of the Dongting Lake (DTL) has been continuously low, and the wetland area and landscape pattern have changed significantly. Considering the obvious spatial heterogeneity of water regime changes in different waters of the DTL, this paper takes two core areas of the South Dongting Lake Nature Reserve (SDLNR) as study areas and analyzes the spatial distribution characteristics of the wetland blue–green landscape patterns by using remote sensing image data and hydrological and meteorological data. The multi-scale correlation between runoff, precipitation, temperature, and evapotranspiration in the SDLNR was studied via cross-wavelet transform analysis. The results show the following: (1) The change in the blue–green spatial patterns in different regions in different periods is inconsistent, and this inconsistency is related to the topography, climate, and human activities in each region; (2) there are seasonal fluctuations in precipitation, air temperature, and evapotranspiration in the SDLNR. Among them, the annual mean temperature shows a rising trend and passes the significance test with 95% confidence, while the annual mean precipitation and annual mean evapotranspiration show no significant change trend; and (3) our Pearson correlation analysis and cross-wavelet change results show that precipitation and temperature are strongly correlated with runoff, with a resonance period of 8–16 months, while the correlation between evapotranspiration and runoff is not significant. We recommend that policymakers establish an effective early warning system and make plans to store water through micro-terrain transformation in possible climate change treatments and strategies.

Keywords: South Dongting Lake Nature Reserve; blue space; green space; precipitation; air temperature

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1. Introduction

A large area of wetland around the world has been lost over the past three centuries, especially during the mid-twentieth century [1]. According to Fluet-Chouinard et al., inland wetlands decreased by 3.4 million km^2 since 1700, mainly due to conversion to croplands [1]. However, changing rainfall patterns are currently affecting wetland distribution—a process acknowledged by the authors but not included in their modeling framework [2]. The Yangtze River Basin's location is characterized by a marine–continental climate interface. This special geographical position makes the Yangtze River Basin very sensitive to climate change [3]. In the summer of 2022, the Yangtze River Basin suffered the biggest meteorological drought and most persistent extreme high temperatures since 1961, and there was a rare phenomenon of "drought in flood season" [4]. On July 28, 2022, the water level of the

Chenglingji Station at the outlet of the Dongting Lake in the main flood season was 25.71 m, which was 5.22 m lower than the average water level for the same period in previous years. The continuous decline in water level has led to the shrinking of the Dongting Lake's water surface, the premature exposure of marshland, an interruption of some reaches of the river, and a shortage in the domestic and production water provided by the river, which has seriously adversely affected the local aquatic ecology and water environment. The impact of climate change has been very obvious, and a growing number of scientists are forecasting more frequent and intense extreme weather events in the future [5–7]. Blue–green space is a term in urban planning that emphasizes the importance of green spaces and natural water flows in cities and belongs to a category of "nature-based solutions (NBSs)" addressing climate change [8]. Green spaces refer to all vegetated areas, such as forests, grasslands, croplands, and other areas dominated by vegetation cover, while blue spaces refer to all natural and artificial water bodies, such as lakes, reservoirs, rivers, and other areas dominated by waterbodies or watercourses [9–12]. Thus, it is imperative to analyze the spatial and temporal variability of the blue–green landscape patterns in the wetland areas of the Dongting Lake and to reveal the main constraints that significantly affect variability so that effective climate adaptation plans for improving the sustainability of the wetland area can be developed.

2. Materials and Methods

2.1. Study Area

The Dongting Lake (DTL) is the first lake connected to the Yangtze River; it is located below the Three Gorges Reservoir in the middle reaches of the Yangtze River and was once the largest freshwater lake in China, with the Xiang, Zi, Yuan, and Li rivers flowing into the lake. The surface area of the DTL has decreased by nearly 50% in the past 100 years due to sediment deposition and reclamation, making it the second-largest freshwater lake in China. The DTL is mainly composed of the East Dongting Lake (East DTL), West Dongting Lake (West DTL), South Dongting Lake (South DTL), Hengling Lake, and other lakes, comprising a complex "river–lake–reservoir" system.

The average monthly water level of the DTL is affected by the water levels of the Xiang, Zi, Yuan, Li, and Yangtze rivers, fluctuating between 20.19 and 30.24 m [13]. Consequently, the DTL presents a special hydrological pattern, meaning that shoals are submerged to form a large body of water in flood season and are exposed during the receding period [14]. Littoral plants such as *Carex* spp. appear in large numbers and grow continuously on the shoal areas almost throughout the receding period, turning mudflats into meadows [15], which makes the blue and green spatial structure of the lake alternate in the flood and drought seasons. For the core area of the DTL, blue space refers to all natural and artificial water bodies in the area, and green space refers to all vegetated areas, including mudflat land, grassy flat land, poplar woodland, and reed land [16]. Extensive studies have been conducted on the characteristics and causes of the water regime changes in the DTL [17,18], the impact of the Three Gorges Project on water regime change [19–21], and the response of the DTL's wetland ecosystem to water level fluctuations [14,22]. However, these studies examined the DTL as a whole without considering the obvious spatial heterogeneity of water regime changes [23]. The South Dongting Lake Nature Reserve (SDTLNR) is located in the southwest of the DTL. It is an important water area that connects the East DTL, West DTL, and Hengling Lake. Its special geographical position plays an extremely important role in regulating the flooding of the Yangtze River.

The South Dongting Lake Nature Reserve (SDTLNR) was listed in the Ramsar Convention in 2002, with a total area of 80,100 hectares. Creeks are intersected with each other, small lakes are scattered, and embankments are crisscrossed in SDTLNR. The SDTLNR is characterized by a continental subtropical monsoon humid climate and has four distinct seasons, featuring a warm and humid summer and a cold and dry winter. The annual precipitation is 1200–1400 mm. The precipitation is concentrated from March to August, as the precipitation in these months accounts for 70% of the yearly precipitation. The precipitation from September to February of the next year is less, accounting for only 30% of the yearly precipitation. The average annual runoff is 973 million m^3. Generally, the annual runoff values of the wet, normal, dry, and extra dry areas are 1.148 billion m^3, 949 million m^3, 770 million m^3, and 625 million m^3, respectively. The fluctuations in surface runoff lead to the dry year, normal water year, and flood year alternations [24]. The distribution of surface runoff is also uneven from season to season. The rainy season spans from March to August, characterized by high levels of precipitation and large runoffs. The dry season takes place from September to February of the next year, with less precipitation and less runoff. It frequently exchanges with the river water of the Yangtze River, which makes it a unique ecosystem and therefore a natural gene pool for various rare and endangered species [24], as well as an important habitat and breeding ground. The SDTLNR is also one of the most important wintering habitats for migratory birds along the East Asian–Australasian Flyway [25]. We selected two core areas (and their buffer zones) in the SDTLNR as our study areas, namely, the Luhu zone and the Wanzihu zone, which have areas of 23,400 hectares and 19,400 hectares, respectively (Figure 1).

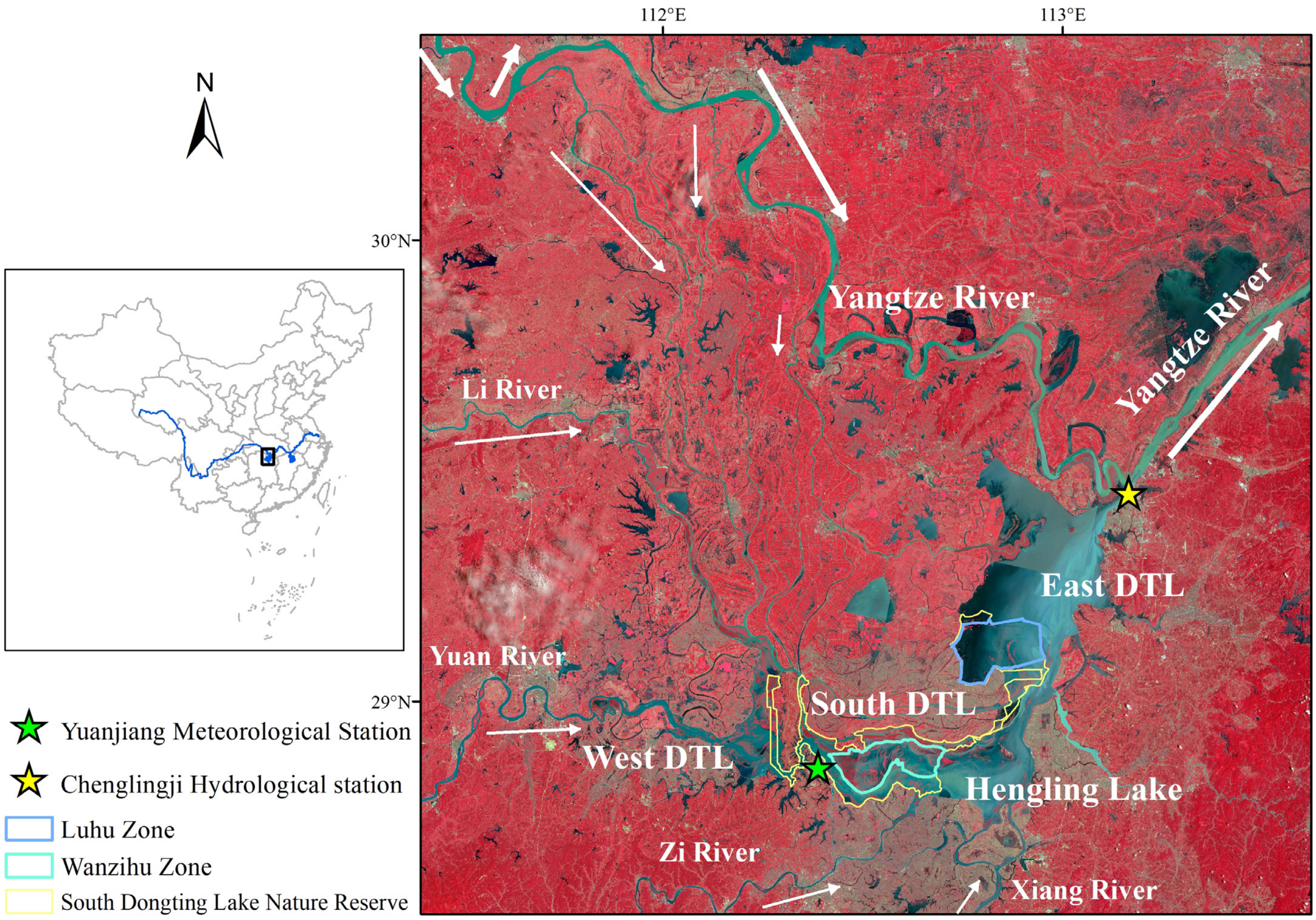

Figure 1. Study areas. The South Dongting Lake Nature Reserve (SDTLNR) is located in the southwest of the Dongting Lake (DTL). The DTL is mainly composed of the East Dongting Lake (East DTL), West Dongting Lake (West DTL), South Dongting Lake (South DTL), Hengling Lake, and other lakes. There are four rivers that flow into the DTL, including the Xiang River, the Yuan River, the Zi River, and the Li River. Some of the water from the Yangtze River flows into the Dongting Lake through tributaries and then flows into the Yangtze River again through the outlet of the Dongting Lake.

2.2. Data Preparation

The original data used in this study were Landsat 8 OLI remote sensing image data, with a strip number of 124 and row number of 40. In order to ensure the quality and high comparability of the data, high-quality remote sensing images with less than 5% cloud cover were selected as often as possible. Considering the seasonal differences in precipitation and surface runoff in the study areas, the study period was divided into a flood period and a drought period. Based on these periods, data from the Landsat 8 Operational Land Imager (OLI) dataset from July 2016, July 2017, and July 2018 were adopted for the flood period, and data from January 2017, January 2018, January 2020, and December 2021 (as the drought period of 2022) were adopted for the drought period. The remote sensing data were downloaded from the Data Center for Science, Chinese Academy of Sciences (http://www.gscloud.cn, accessed on 1 January 2023), and the data had a spatial resolution of 30 m. Hydrological data were obtained from the Ministry of Water Resources of the Yangtze River Water Resources Commission (http://www.cjw.gov.cn/zwzc/zjgb/, accessed on 1 March 2023), and the site was the Chenglingji hydrological station, which was shown in Figure 1. The Chenglingji hydrological station is located at the outlet of the Dongting Lake Basin, which is a barometer of the water regime of Dongting Lake. Meteorological data were obtained from the geographic science and resources of the Chinese Academy of Sciences Institute of Resources and Environment Science and Data Center (https://www.resdc.cn/data.aspx?DATAID=230, accessed on 1 March 2023), and the site was Yuanjiang station, which was shown in Figure 1. The meteorological factors selected included daily precipitation (20–20 mm), daily average temperature (°C), and daily average evaporation (mm). The time range was from 1 January 2010 to 31 December 2022.

2.3. Methods

2.3.1. Modified Normalized Difference Water Index (MNDWI)

With the assistance of ENVI5.3 software (version 5.3.1), the modified normalized difference water index (MNDWI) was calculated after the geometric and radiometric correction of the Landsat OLI images. Then, the water body was extracted using a threshold method based on the MNDWI. The extracted water space was blue space. Because the study areas are the core and buffer areas of the nature reserve, the remaining spaces in the area (i.e., except water space) were swamp land, grassy flat land, poplar woodland, and reed land—collectively referred to as green space in this study.

The band operation expression of the MNDWI was (B1 − B2)/(B1 + B2), where B1 corresponds to the reflectance of the green band and B2 corresponds to the reflectance of the mid-infrared band (i.e., SWIR 1 band of Landsat 8 OLI).

2.3.2. Landscape Pattern Index

The landscape pattern index method is commonly used in landscape pattern analysis. The landscape pattern index can be used to quantitatively describe the evolution of landscape patterns. By considering the relationship between landscape pattern and landscape process, the difference in landscape spatial pattern can be better expounded. The degrees of fragmentation, connectivity, and diversity among landscapes are important attribute characteristics in large-scale studies such as those involving nature reserves [26,27]. Therefore, the patch density index (PD), landscape shape index (LSI), and patch combination index (COHESION) were selected to quantitatively describe the evolution characteristics of the blue–green spaces at the patch-type level. In addition, the Shannon diversity index (SHDI), contagion index (CONTAG), and aggregation index (AI) were selected to analyze the dynamic changes in the blue–green spaces at the landscape level. The ecological significance of each index and their calculation formulas are detailed in [28,29].

2.3.3. Cross-Wavelet Transform (XWT)

The cross-wavelet transform method (XWT) [30,31] was used to analyze the relationship between the Dongting Lake outlet discharge and climate change. It was carried out using MATLAB software version R2023a. The cross-wavelet transform is developed based on traditional wavelet analysis and the continuous wavelet transform (CWT) for examining relationships in time frequency space between two time series. Suppose that the two time series are $X = \{x_1, x_2, \cdots, x_n\}$ and $Y = \{y_1, y_2, \cdots .y_n\}$, respectively, and that the corresponding continuous wavelet transforms are $W_n^X(s)$ and $W_n^Y(s)$. Then, the cross-wavelet transform between them is defined as $W_n^{XY} = W_n^X(s)W_n^{Y*}(s)$, where $W_n^{Y*}(s)$ denotes the complex conjugation of $W_n^Y(s)$. The cross-wavelet power is defined as $\left|W_n^{XY}(S)\right|$.

3. Results

3.1. Landscape Pattern Analysis of Blue and Green Spaces

3.1.1. Flood Period

The landscape patterns of the blue and green spaces in the flood period are shown in Figure 2. In the Luhu zone, the proportions of water area in 2016, 2017, and 2018 were 95.16%, 83.51%, and 33.46%, respectively (as shown in Figure 3), showing a decreasing trend year by year. It should be noted that the water area decreased significantly by 59.9% in 2018. As shown in Figure 4, the patch density index (PD) and landscape shape index (LSI) increased year by year from 2016 to 2018. At the landscape level, the contagion index (CONTAG) decreased, while the Shannon diversity index (SHDI) increased continuously. The changes in these indexes are reflected in the spatial distribution of the water area (Figure 2); in 2016, the water area was relatively large, covering almost the whole area and showing a relatively large water patch, while from 2017 to 2018, the water area gradually shrank and showed a trend of fragmentation.

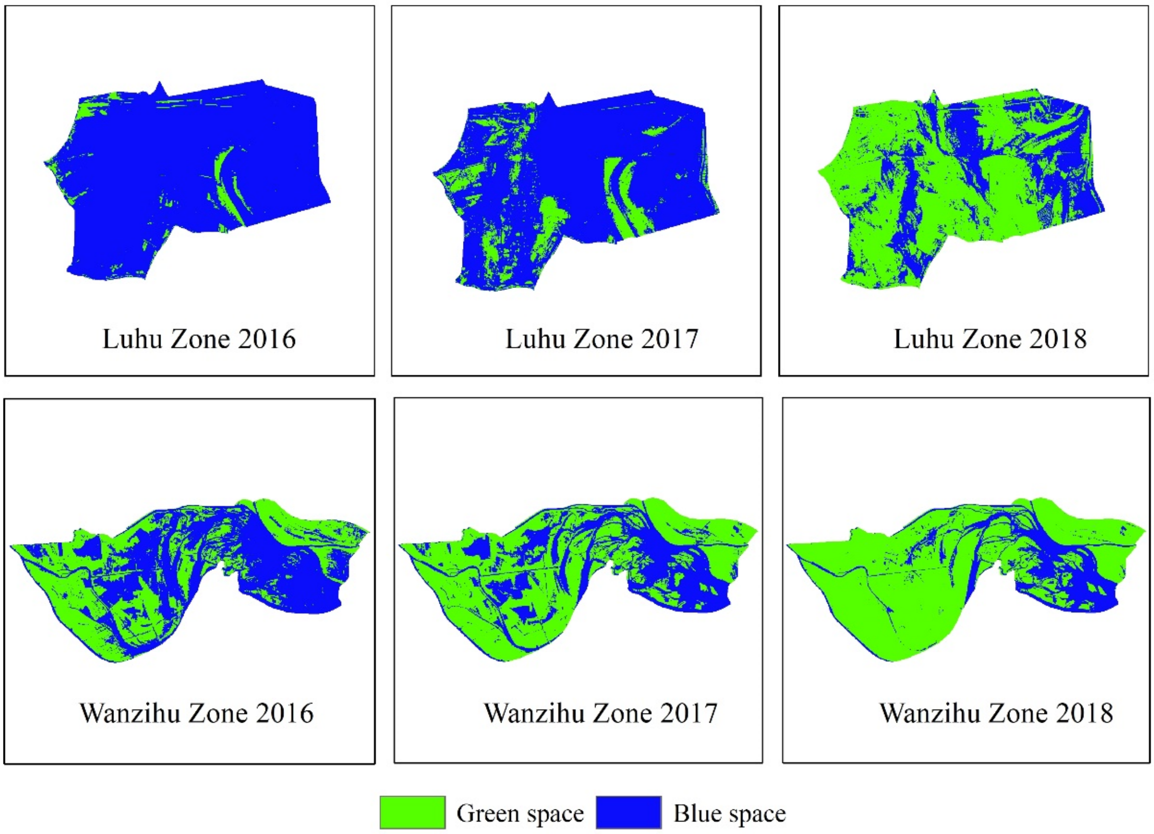

Figure 2. Landscape patterns of blue and green spaces in the flood period.

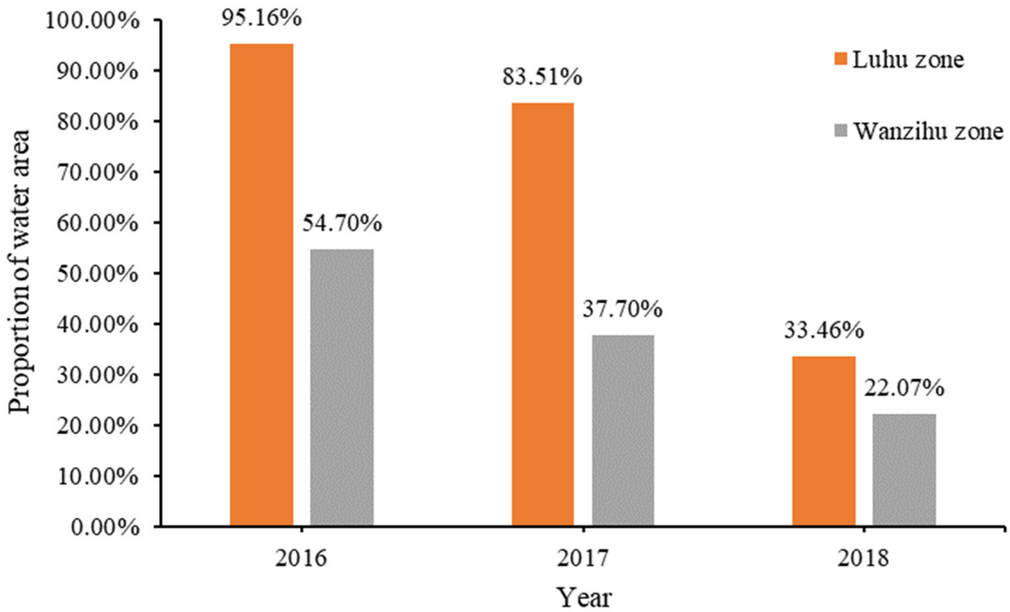

Figure 3. Proportions of water area in the flood period.

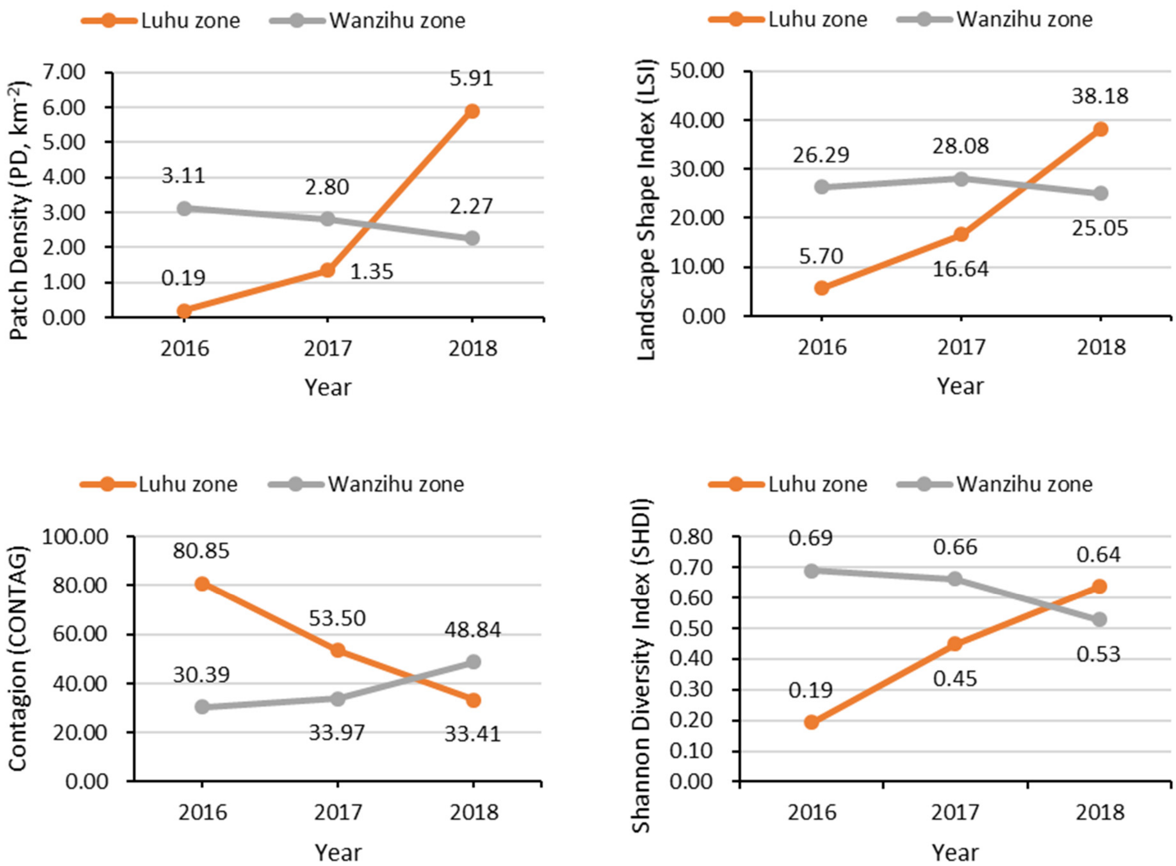

Figure 4. Landscape index during the flood period.

In the Wanzihu zone, the proportions of water area in 2016, 2017, and 2018 were 54.70%, 37.70%, and 22.07%, respectively, showing a decreasing trend year by year (Figure 3). As shown in Figure 4, the patch density index (PD) decreased continuously year by year, while the landscape shape index (LSI) increased from 2016 to 2017 and then decreased from 2017 to 2018. At the landscape level, the contagion index (CONTAG) increased year by year, while the Shannon diversity index (SHDI) decreased year by year. The contagion index (CONTAG) represents the adjacent relationship between patch types. The small value indicates that the blue and green spaces in the wetland landscape are densely combined, while the large value indicates that the dominant patches in the landscape are characterized by good connectivity. The changes in these landscape indexes are related to the complex topography of the Wanzihu zone. The water system in this area is complex; the water network is vertical and horizontal, and the wetland patches have great spatial heterogeneity, which is positively correlated with the water-covered area.

It can be seen that the landscape pattern and its dynamic changes are different in different regions during the flood period, which is particularly noteworthy in ecological restoration.

3.1.2. Drought Period

The landscape patterns of the blue and green spaces in the drought period are shown in Figure 5. In the Luhu zone, the proportion of water area varied from 9.88% in 2018 to 0.95% in 2022 (Figure 6). As shown in Figure 7, the patch density index (PD) increased from 2017 to 2018 and then decreased from 2018 to 2022, with peak values appearing in 2018. The landscape shape index (LSI) increased from 2017 to 2018, decreased from 2018 to 2020, and then increased again from 2020 to 2022.

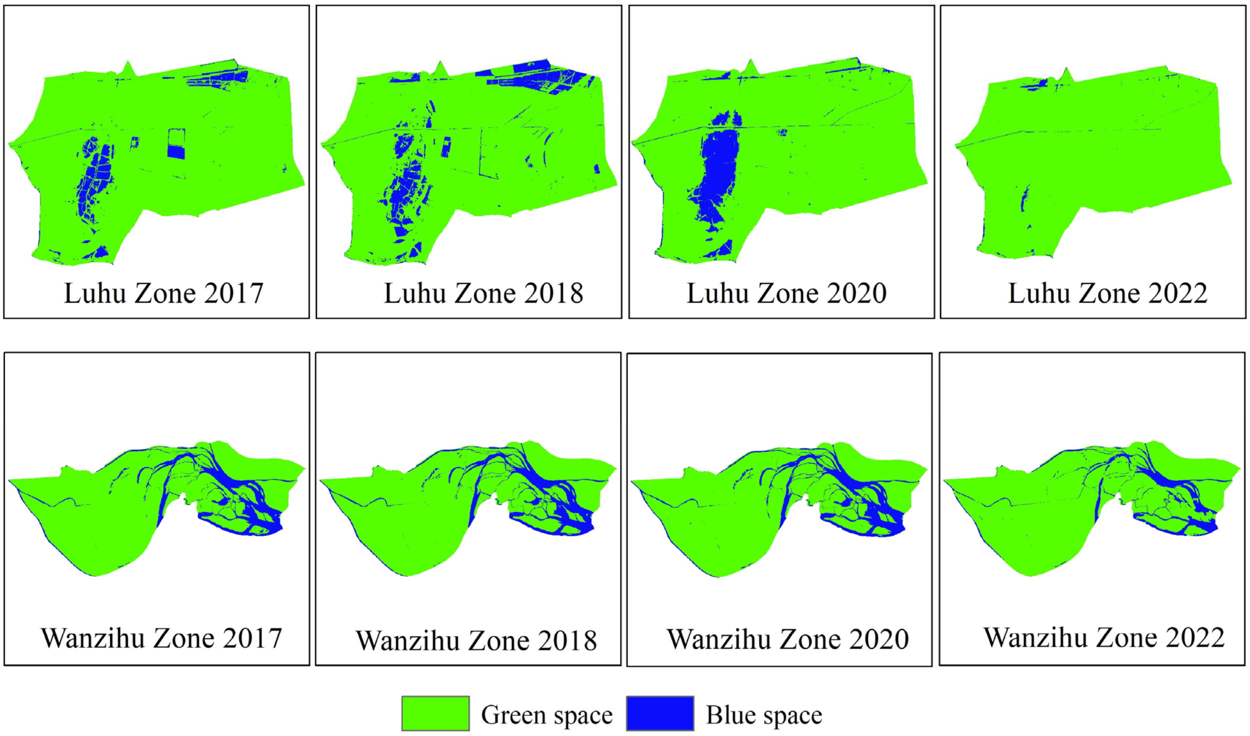

Figure 5. Landscape pattern of blue and green spaces in the drought period.

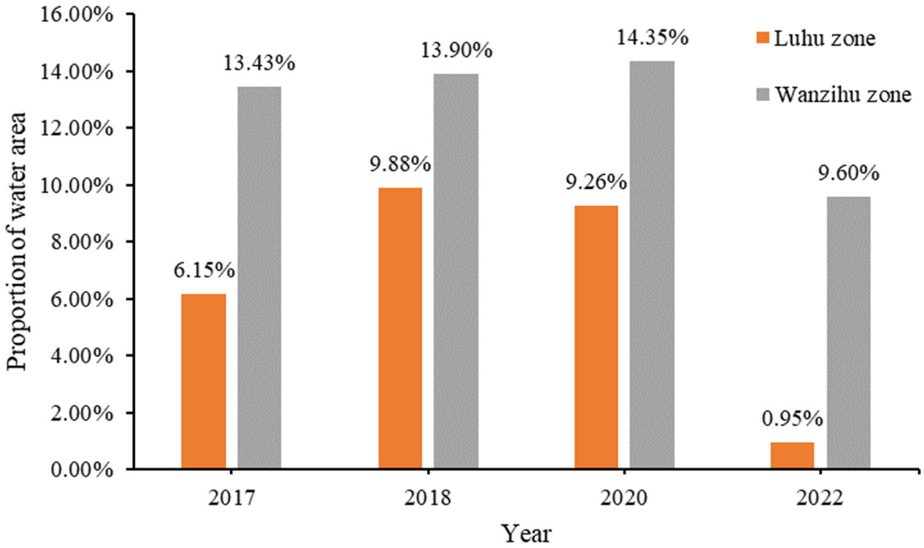

Figure 6. Proportion of water area in the drought period.

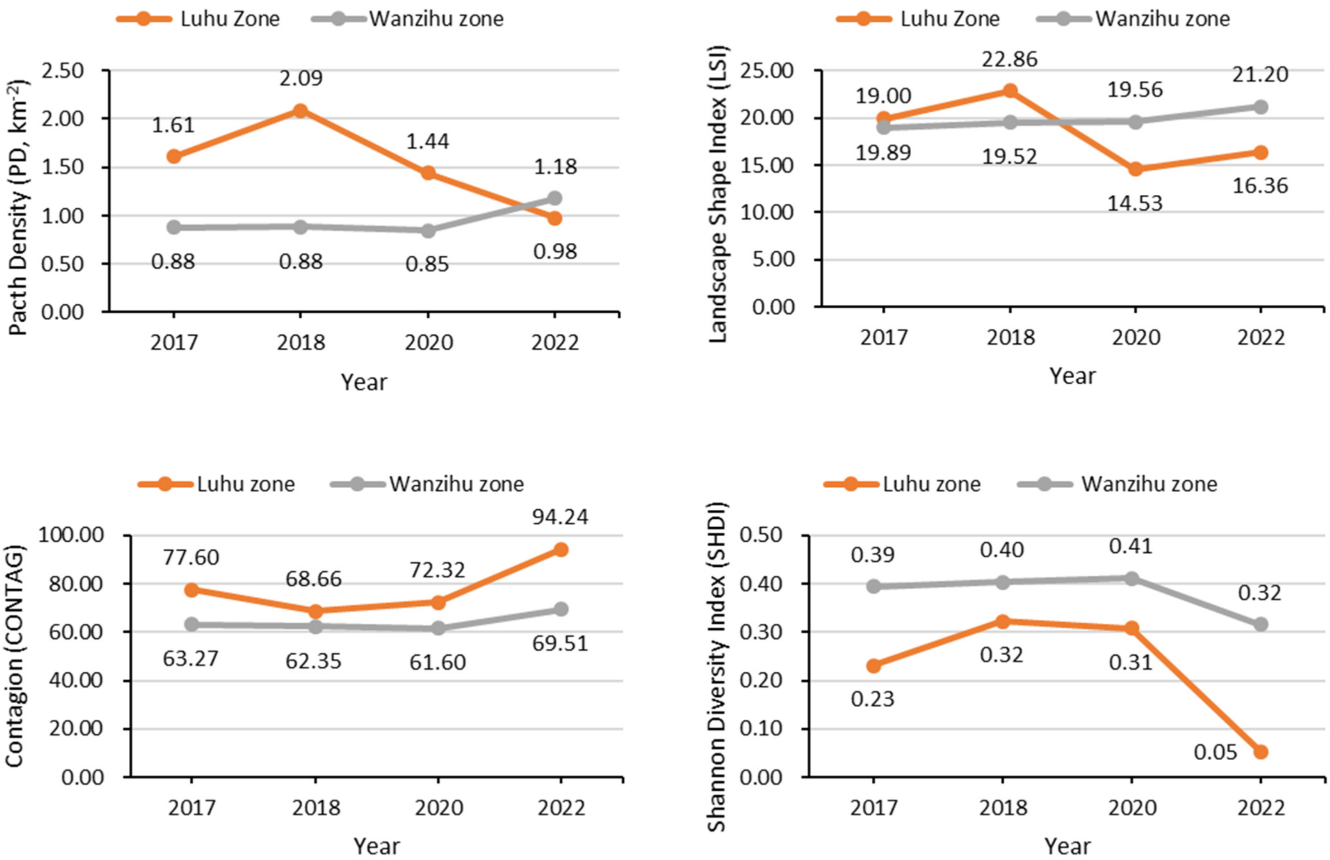

Figure 7. Landscape index during the drought period.

The lowest landscape shape index (LSI) value appeared in 2020, potentially resulting from the local government's transformation of the landscape. Before 2017, there were a lot of low dams and seine nets for fishing in the South Dongting Lake. In 2017 and 2018, the local government implemented a special campaign to remove the low fence and seine nets, which improved the hydrological connectivity of the wetland and made the wetland patches more structured. Therefore, the landscape shape index (LSI) decreased in 2020. At the landscape level, the contagion index (CONTAG) showed a concave increase and reached the maximum in 2022, while the Shannon diversity index (SHDI) showed a convex decline and reached the minimum in 2022. This is due to the extreme drought in the drought period of 2022. It can be seen from Figure 8 that the monthly average precipitation in December 2021 was only 20.6 mm, while the monthly average precipitation values for January 2017, January 2018, and January 2020 were 38.9 mm, 107.7 mm, and 168.5 mm, respectively. The increase in the CONTAG resulted from the increase in the vegetation coverage of the dominant patches in the landscape, while the SHDI decreased accordingly.

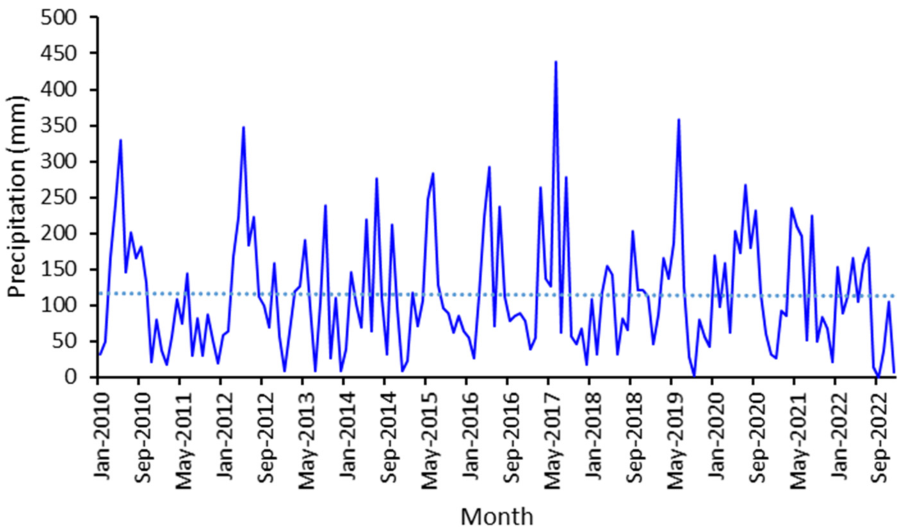

Figure 8. Monthly precipitation in the SDTLNR from January 2010 to December 2022.

In the Wanzihu zone, the proportion of water area changed little in 2017, 2018, and 2020, ranging from 13.43% to 14.35%, while it dropped to 9.60% in 2022 (Figure 6). Accordingly, the patch density index (PD) and landscape shape index (LSI) experienced growth in 2022 (Figure 7). This was because the water area shrunk in 2022, and the wetland patches became more fragmented. At the landscape level, the contagion index (CONTAG) increased slowly, while the Shannon diversity index (SHDI) decreased, similar to the situation in the Luhu zone.

3.2. Relationship between Runoff and Meteorological Factors

As the blue space refers to water bodies and the size of the water area in the SDTLNR determines the volume of outlet runoff, the relationship between outlet runoff and meteorological factors in SDTLNR reflects the relationship between blue–green spatial structure and meteorological factors. The runoff of the Chenglingji hydrology station was analyzed with meteorological factors.

3.2.1. Relationship between Runoff and Precipitation

Precipitation is an important factor affecting the lake water area, and the lake water area's response to precipitation can be understood by analyzing the relationship between runoff and precipitation. As shown in Figures 8 and 9, the monthly precipitation of the SDTLNR showed periodic changes from 2010 to 2022, but the inter-annual precipitation showed no significant change trend. As shown in Figure 10, there is a good consistency between the annual fluctuations in precipitation and runoff on the monthly scale. The correlation between runoff and precipitation was analyzed via SPSS. The results showed that the correlation coefficient between precipitation and runoff was 0.602, passing the significance test with a confidence level of 95%. The XWT of precipitation and runoff is shown in Figure 11. The 5% significance level against red noise is shown as a thick contour. The relative phase relationship is shown via arrows (with in-phase pointing right, anti-phase pointing left, and runoff leading precipitation by 90° pointing straight down).

The horizontal axis is the time axis, representing the 52 months from July 2018 to October 2022. In general, runoff and precipitation had a good correlation for a total of 7–16 months considering the whole time period, and this correlation passed the significance test. It should also be noted that there was a significantly lower correlation in the 8–10 months from April 2019 to October 2020, indicating that there may be other factors affecting runoff on this scale besides precipitation factors such as the impoundment and discharge of the Three Gorges Dam in the upper reaches of the Dongting Lake. Wang [32] indicated that the peak flow value in the flood period after the construction of TGD was significantly weakened based on an analysis of the variations in flow trends in the year. The operation of the TGD resulted in a decrease of 26.357 billion m^3 in the annual runoff of the DTL.

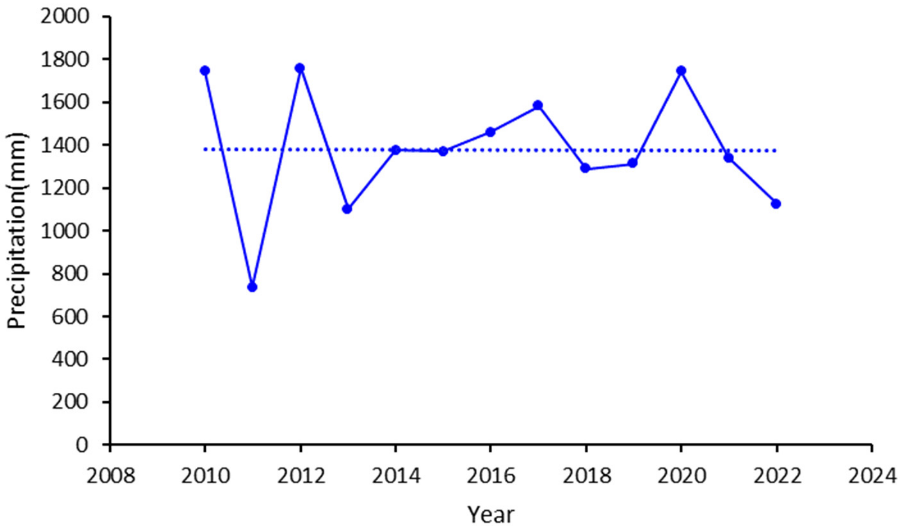

Figure 9. The inter-annual precipitation in the SDTLNR from 2010 to 2022.

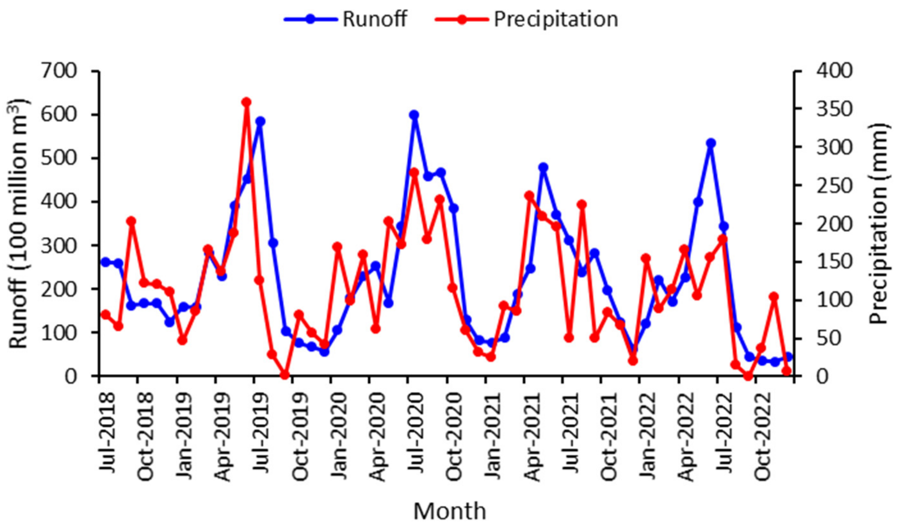

Figure 10. The monthly precipitation in the SDTLNR and runoff in the outlet of the DTL from July 2018 to December 2022.

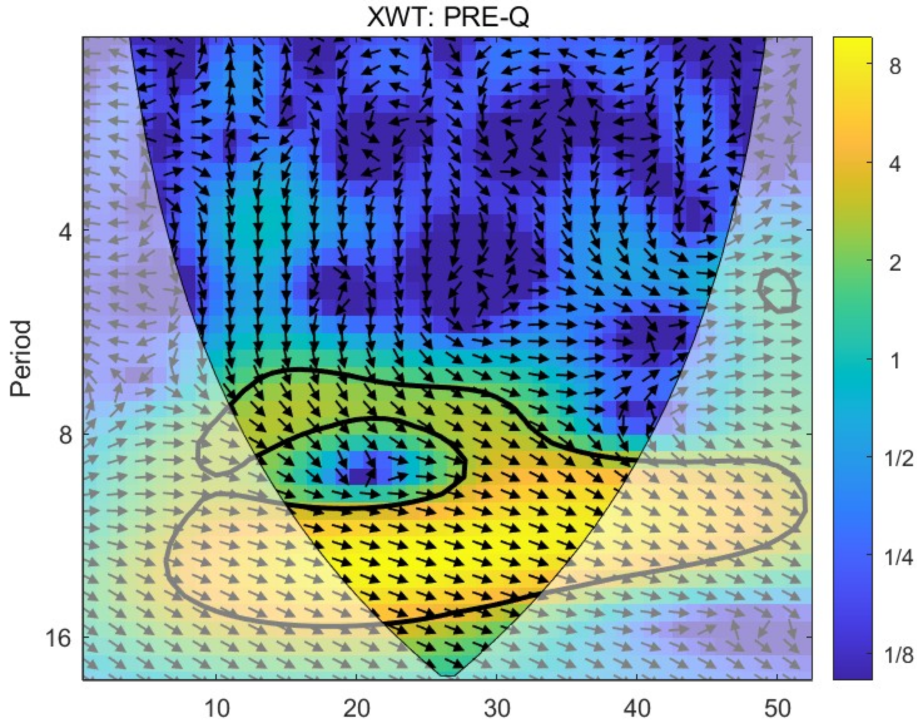

Figure 11. The XWT of precipitation and runoff.

3.2.2. Correlation between Runoff and Air Temperature

As shown in Figures 12 and 13, the monthly mean temperature in the SDTLNR changed periodically from 2010 to 2022, and the inter-annual mean temperature presents a very significant rising trend (F = 12.045, p = 0.005), with a warming rate of 0.1033 °C/a (t = 3.471, p = 0.005). As shown in Figure 14, there is good agreement between the annual fluctuation in temperature and runoff on the monthly scale. The correlation coefficient between temperature and runoff was 0.563, passing the significance test with a confidence level of 95%. As shown in Figure 15, runoff and temperature had a good correlation for a period of 8–16 months considering the whole time period, and this correlation passed the significance test.

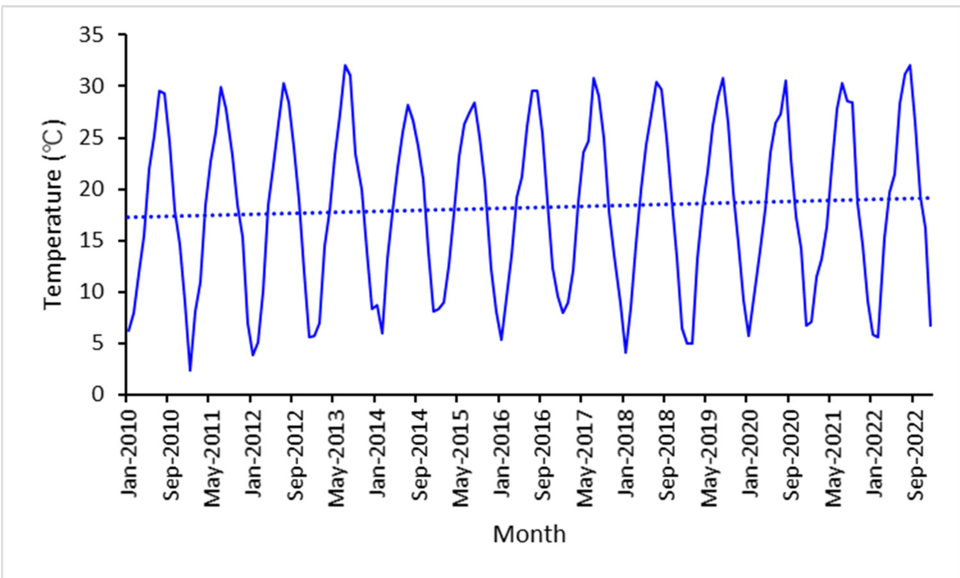

Figure 12. The monthly temperature in the SDTLNR from January 2010 to December 2022.

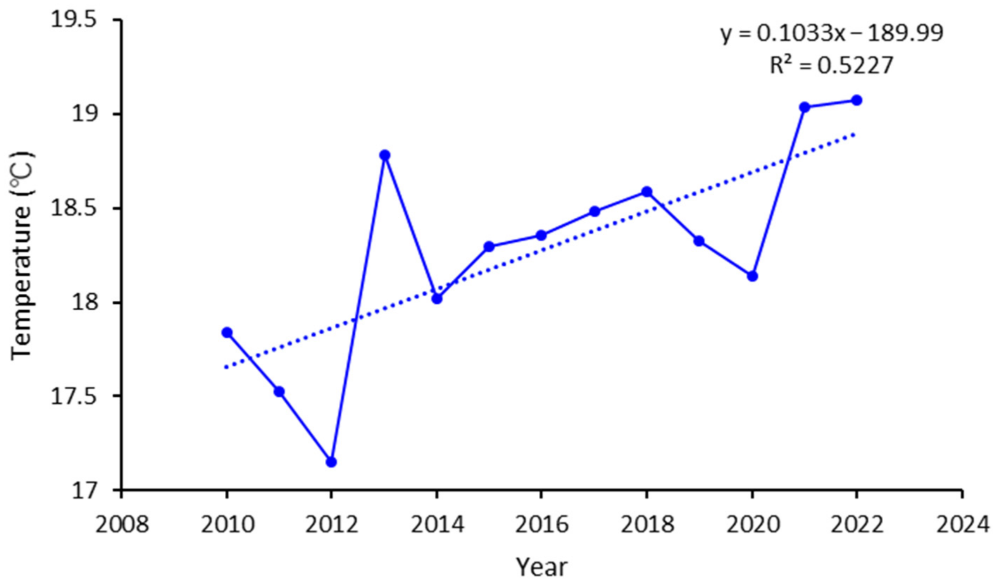

Figure 13. The inter-annual temperature in the SDTLNR from 2010 to 2022.

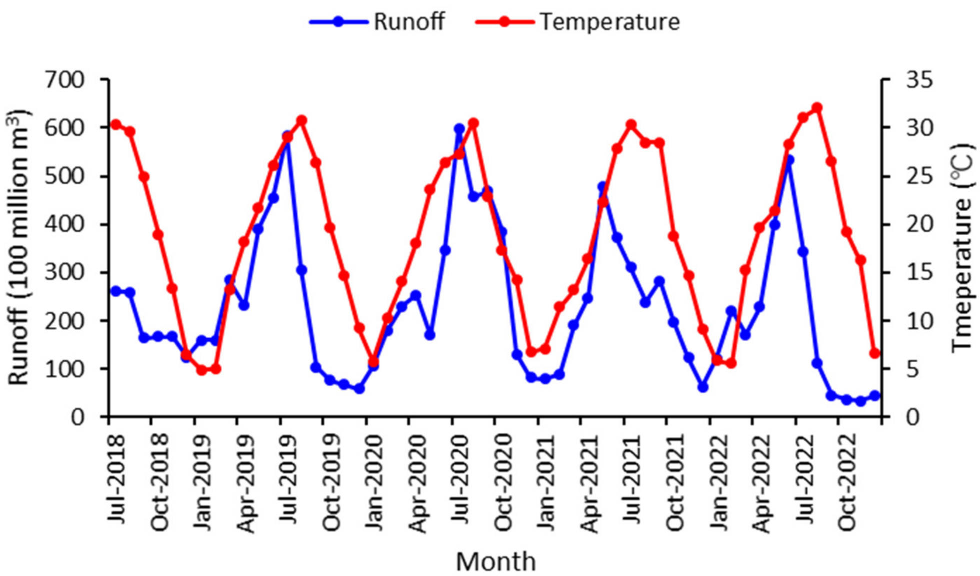

Figure 14. The monthly temperature in the SDTLNR and runoff in the outlet of the DTL from July 2018 to December 2022.

3.2.3. Correlation between Runoff and Evapotranspiration

As shown in Figures 16 and 17, the monthly mean evapotranspiration in the SDTLNR changed periodically from 2010 to 2022, but the interannual average evapotranspiration did not change significantly. As shown in Figure 18, there is a good agreement between the annual fluctuation in evapotranspiration and runoff on the monthly scale. The correlation coefficient between evapotranspiration and runoff was 0.213, not reaching the level required for significance. This indicated that the periodic fluctuation in evapotranspiration was caused by seasonal changes and that it had no effect on runoff.

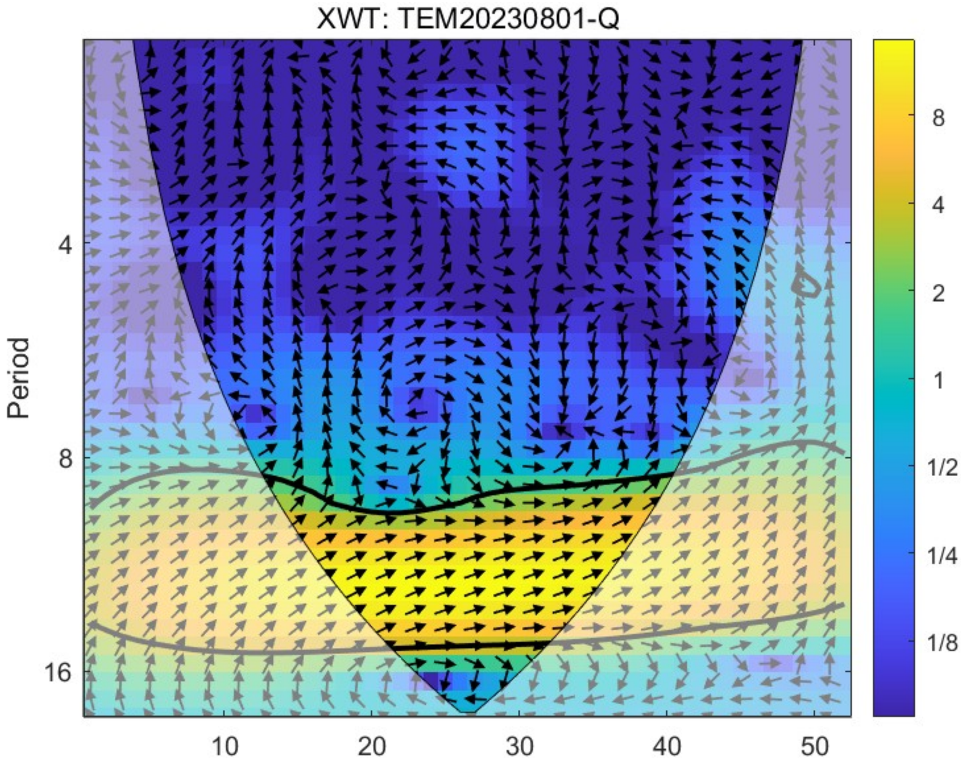

Figure 15. The XWT of temperature and runoff.

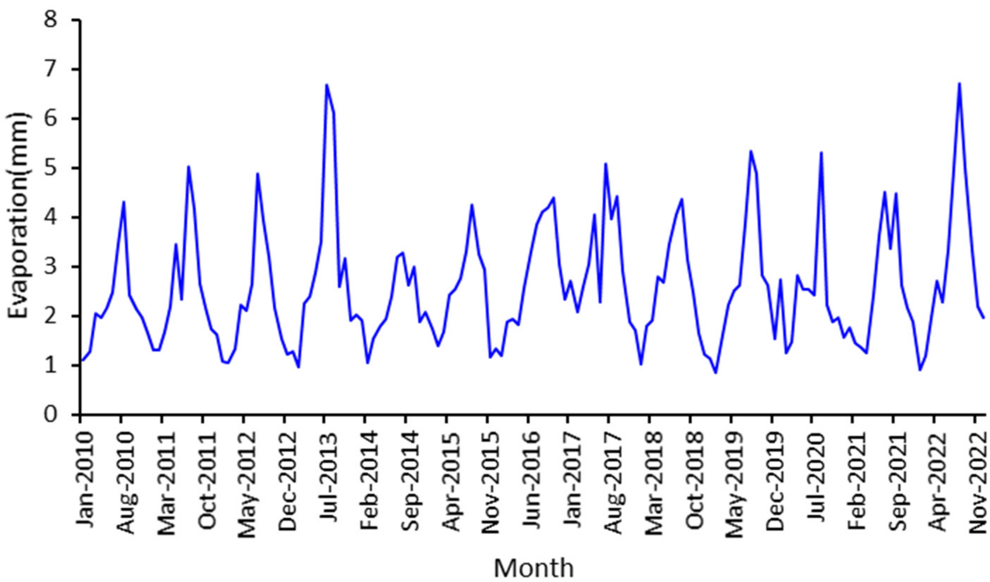

Figure 16. The monthly evaporation in the SDTLNR from January 2010 to December 2022.

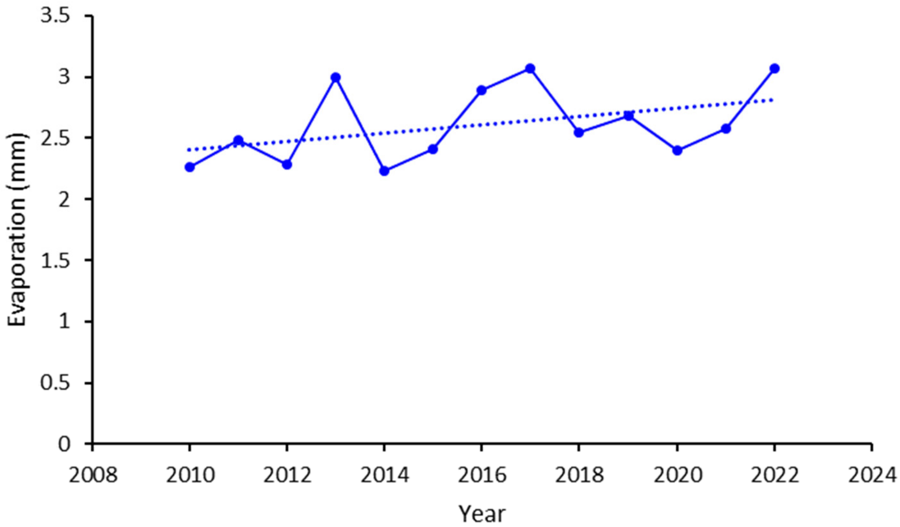

Figure 17. The inter-annual evaporation in the SDTLNR from 2010 to 2022.

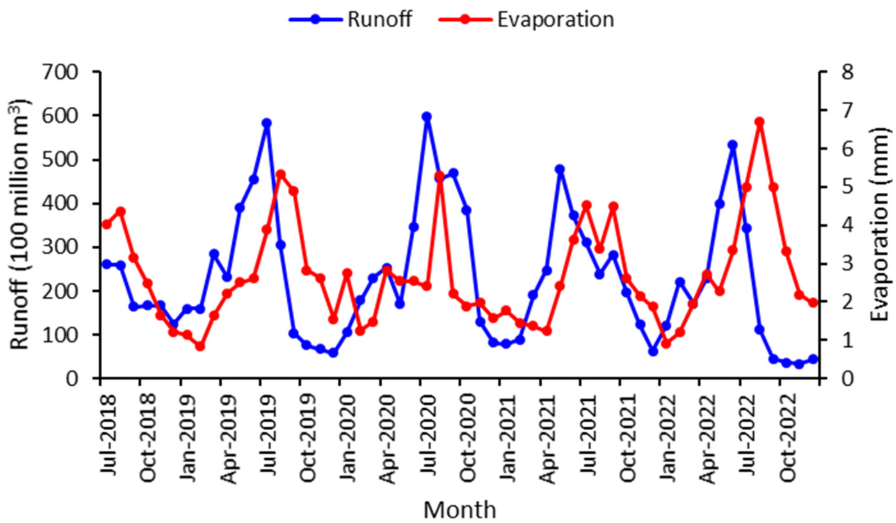

Figure 18. The monthly evaporation in the SDTLNR and runoff in the outlet of the DTL from July 2018 to December 2022.

4. Discussion

4.1. Driving Forces for Blue–Green Space Alternations

The drivers behind changes in the hydrological regime are classified into human activities (dam operation and land use change) and climate change (precipitation, temperature, and evaporation). According to Huang et al., the runoff in the Dongting Lake was mainly affected by climate change from 1984 to 2004 and by human activities from 2005 to 2019 [33]. However, our study period is after the operation of the Three Gorges Dam (2003). Therefore, the purpose of this study was to gain insight into the correlation between climate change and runoff amidst the background of human activities that have been implemented since 2010. In recent decades, the water cycle in the basin has been affected by global warming, leading to changes in the spatial and temporal patterns of precipitation [34]. The dominant meteorological variables in the Dongting Lake were the precipitation regime and temperature-related indicators [35]. The rising temperature and significant increase in the frequency of extreme floods and droughts led to the alternations in blue–green spatial structures in the SDTLNR.

4.2. Ecological Response to Blue–Green Space Alternations

It is vital that blue–green space alternates regularly in the SDTLNR to maintain biodiversity and ecosystem health. However, the blue–green alternations have become irregular as a result of changes to the natural hydrological regime (flow and water level) because of climate change [32,36]. The irregular blue–green spatial structure alternations have impacts on wetland plants, migratory waterfowl and fish, and mammals, leading to a loss of biodiversity [37]. The presence of *Carex praticola* (meadow sedge) increased due to an earlier and longer period of water recession, and plants grown in the upper shoal crowded out the plants grown in the lower shoal, leading to a positive succession of wetland vegetation [38]. Moreover, the vegetation dynamics directly affected the habitat suitability for migratory waterfowl. The numbers of hooded crane (*Grus monacha*), white crane (*G. leucogeranus*), grey crane (*G. grus*), and white-naped crane (*G. vipio*) are reducing as a result of the decreasing mudflat and water area and accelerating fragmentation in the East DTL [39]. The increase in shoal outcrop area in the drought period might also have a systematic and profound effect on the reproduction of fish, affecting the stickiness of their eggs [40]. The recession period is also the most challenging time for finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*) protection due to the limited amount of suitable habitat [41]. Specifically, the decrease in water level will cause food shortage and a high risk of standing for the porpoises, resulting in an increase in mortality and a decline in population [42].

4.3. Mitigation and Adaptation

Since the UNFCCC Paris Agreement came into force after 2015, international climate policies have centered around three pillars: mitigation, adaptation, and loss and damage [43]. The 27th Conference of the Parties (COP27) was held in Sharm El-Sheikh (Egypt) from 6 to 18 November 2022, and one of the essential topics discussed was the need to implement mitigation and adaptation measures to cope with climate change. This need was addressed in item 24 of the Implementation Plan of COP27, which "Emphasizes the importance of protecting, conserving and restoring water and water-related ecosystems, including river basins, aquifers, and lakes, and urges Parties to further integrate water into adaptation efforts" [44,45].

Therefore, it is crucial for policymakers to develop a package of wetland management adaptation methods for possible climate change treatments and strategies.

Firstly, the need to establish an effective early warning system has been highlighted. This warning system should mainly include two modules: an information monitoring system and a pre-control countermeasure system [46,47]. Decision makers can make more effective plans if information about the dynamics of landscape structures and the state of ecosystems is available.

Secondly, an effective strategy for coping with drought is to store water in small puddles and depressions, which can be established through micro-terrain transformation, shifting from low inside terrain to high outside terrain.

5. Conclusions

In this paper, based on Landsat OLI 8 images and hydrological and meteorological data, the spatial and temporal variations in the blue–green landscape patterns in the core areas of the SDTLNR were analyzed, and the multi-scale correlations between precipitation, temperature, evapotranspiration, and runoff were studied using the cross-wavelet transform method. The spatial–temporal variations in blue–green landscape patterns were related to the topography, climate, and human activities in each area. It was shown that precipitation and temperature had a strong correlation with runoff, while the correlation between evapotranspiration and runoff was not significant. We recommend that policymakers establish an effective early warning system and make plans to store water through micro-terrain transformation in climate change treatments and strategies.

The correlation between runoff, precipitation, and temperature in the SDTLNR was preliminarily analyzed from the perspective of meteorological factors in this paper. However, regarding the Dongting Lake, its landscape pattern and hydrological rhythm are affected by many complex factors, especially the impact of human activities, such as the construction of the Three Gorges Dam, and the underlying mechanism of these factors needs to be comprehensively studied further.

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