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Attribution Analysis on Areal Change of Main Wetland and Its Influence on Runoff in the Naolihe River Basin

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Abstract: Wetlands have powerful runoff regulation functions, which can effectively store and retain surface runoff. The runoff regulation function of wetlands is affected by wetland areas, which affect the capacity of flood control. To explore the law of the area change of the main wetlands of the Naolihe River Basin (MWNRB), the visual interpretation method was used to extract wetlands. To identify the reasons for area changes in the MWNRB, the maximum likelihood method, minimum distance method, and neural network method were used to classify land use types from remote sensing images; the M-K variation point test and Theil-Sen trend analysis were used to test the variation point and calculate the trend of precipitation and temperature series. To clarify the influence of wetland areas on runoff, the Gini coefficient and SRI of runoff were used to calculate runoff temporal inhomogeneity. The results showed that the area of the MWNRB obviously decreased, with 74.5×10^6 m^2/year from 1993 to 2008, and increased slowly from 2008 to 2015, with 27.7×10^6 m^2/year. From 1993 to 2008, 50.74% and 38.87% of wetlands were transformed into paddy fields and dry fields, respectively. From 2008 to 2015, 61.69% and 7.76% of wetlands were transformed from paddy fields and dry fields, respectively. The temperature of the MWNRB increased slowly by 0.04 °C/year from 1993 to 2008 and increased obviously by 0.16 °C/year from 2008 to 2015. The precipitation decreased by 5.6–8.1 mm/year and increased by 16.6–41.2 mm/year in 1993–2008 and 2008–2015, respectively. Compared with precipitation and temperature, land use change caused by human activities is the main cause of wetland area change. The area change of the MWNRB has a certain influence on the runoff regulation and storage capacity. The Gini coefficient and SRI index increased from 0.002/year (0.008) to 0.023/year from 1993 to 2008 and decreased from 0.046/year (0.045) to 0.161/year from 2008 to 2015, respectively.

Keywords: wetland; area change; remote sensing; runoff; human activity

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1. Introduction

Wetlands are natural resources on which human beings depend for existence, known as the 'kidney of the earth' [1–6]. Wetlands perform important ecological functions such as improving water quality, maintaining rich biodiversity [7–9], regulating the regional climate through the differences in albedo, heat capacity, roughness, and energy exchange between wetlands and other land use types [10], and affect the regional runoff process [11,12] by reducing or avoiding flood disasters and maintaining a stable water supply [13–17].

Wetlands are extremely sensitive to climate change and human activities. In recent years, under the interference of climate change and human activities, wetland areas have changed tremendously. The wetland area changes caused by climate change are due to changes in the form and amount of precipitation [18,19] and an increase in temperature leading to a decrease in regional water resources [20]. Moreover, in most regions, the most direct and strongest driving factor for wetland area change is human activities [21]. With the increase in population, the rapid development of industrialization, urbanization, and regional economies, a large number of wetlands have been converted to cultivated land and grassland [22]. The wetlands have suffered huge losses, and the runoff regulation function of wetlands has also been destroyed. Conserving wetlands and maintaining the runoff regulation function of wetlands has caught international attention and has become a research focus in the ecosystem.

To obtain basic data for research on conserving wetlands and maintaining the runoff regulation function of wetlands, remote sensing technology with a wide monitoring range, strong timeliness, no direct contact with measured targets, and quantitative information [23] has been widely used [24–29]. Among many remote sensing technologies, the maximum likelihood method with good stability by dividing the pixels to be classified into the class with the highest probability [30], the minimum distance method with fast operation speed by calculating the minimum distance between the pixel vector to be classified and the center vector of each category [31], and the neural network method with strong fault tolerance and high accuracy by integrating prior knowledge into network learning and making maximum use of it [32] are widely used [33–35].

With wetland area changes, the regional hydrological conditions will be affected [36], especially the runoff regulation and storage function [15]. Among the indexes describing runoff regulation and storage function, the Gini coefficient calculates the area of the Lorenz curve to show the uniformity of runoff distribution [37], and the streamflow regulation index (SRI) compares the variation coefficients of precipitation and runoff to show the runoff regulation and storage function in a region.

The main wetlands of the Naolihe River Basin (MWNRB), located in the Sanjiang Plain, Heilongjiang Province, China, is the largest wetland distribution region and has an important impact on hydrological conditions in the basin. However, in the past ten years, there have been few studies on the impact of wetland area changes on runoff in the MWNRB.

Therefore, the area change of the MWNRB, its causes, and its impact on runoff from 1993 to 2015 were studied. Firstly, according to the field investigation results combined with visual interpretation methods, the MWNRB was identified, and the area change of the MWNRB was analyzed. Based on the optimization of the maximum likelihood method, minimum distance method, and neural network classification method, the land use types in the MWNRB were distinguished, and the area of each land use type was calculated. According to the transformation of land use types, the influence of human activities on the area change of the MWNRB was analyzed and revealed. Combined with precipitation and temperature, the influence of climate change on the area change of the MWNRB was analyzed. Combined with the Gini coefficient and the SRI of runoff, and compared with the area change of the MWNRB, the influence of wetland area change on runoff regulation and storage function was analyzed.

2. Materials and Methods

2.1. Study Area

The MWNRB is composed of swamp meadow wetlands and river wetlands. The swamp meadow wetlands are marshy meadows distributed in the MWNRB, which developed under the conditions of low terrain, poor drainage, excessive damp soil, and poor permeability. The river wetlands are the riverbeds of some permanent rivers and reservoirs with an area of fewer than 10^6 m^2 in the Naolihe River Basin. The MWNRB is the largest wetland distribution region in the Sanjiang Plain, which is located in the Naolihe River, Waiqixinghe River, the middle and lower reaches of Qixinghe River, and Qixinghe River Nature Reserve, all of which belong to the Naolihe River system (Figure 1). The Naolihe River, which is 596 km long, is a main tributary of the Wusuli River, originating from Wanda Mountain. The MWNRB is located in the temperate, humid, semi-humid continental monsoon climate zone. The annual average precipitation is 518 mm, which is mostly concentrated in June–September. The average annual temperature is 3.5 °C, the extreme minimum temperature is −37.2 °C, and the extreme maximum temperature is 36.6 °C.

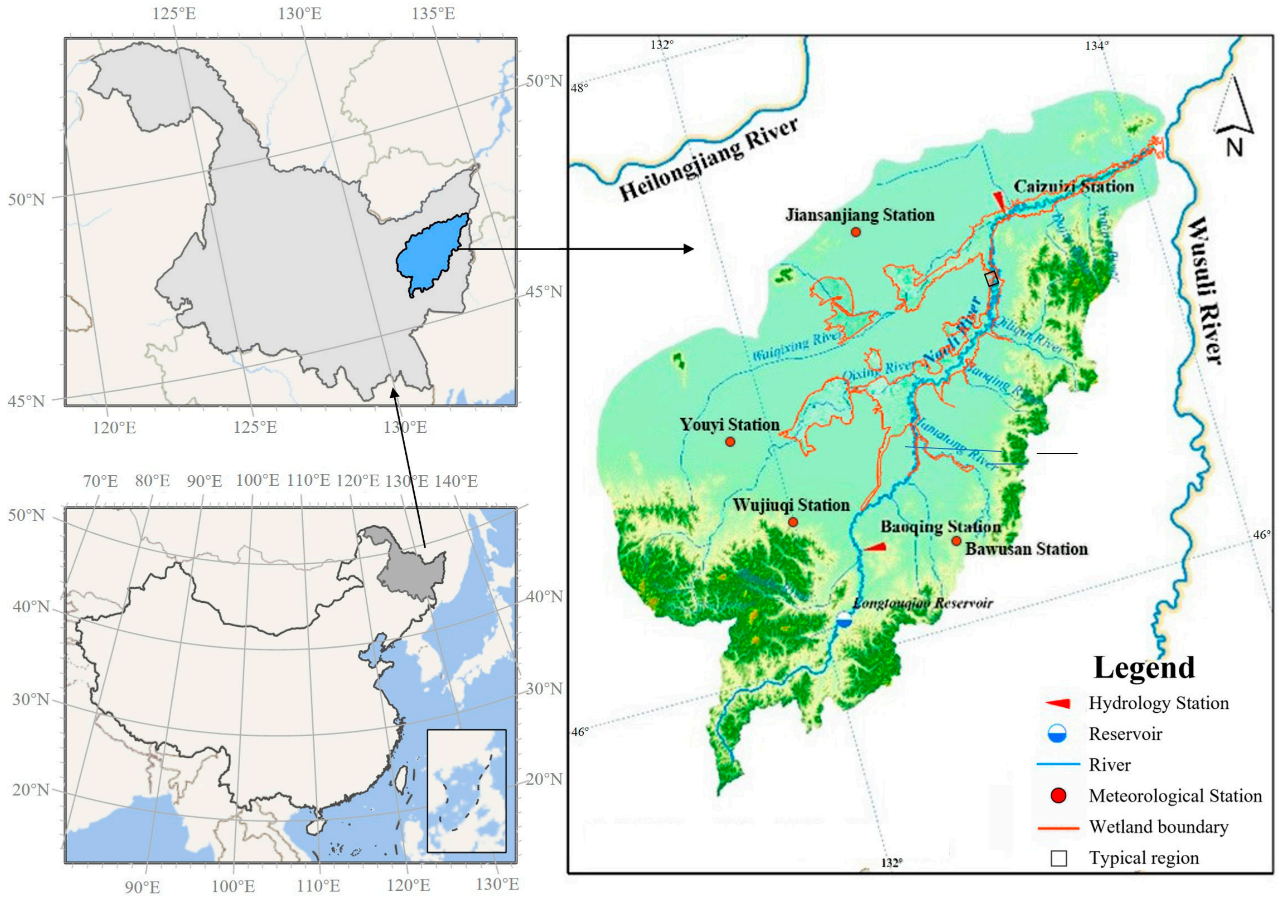

Figure 1. Study Area.

2.2. Data Sources

The multi-temporal remotely-sensed Landsat data of the Enhanced Thematic Mapper (ETM+) and Operational Land Image (OLI) from 1993 to 2015 were obtained from the Earth Resources Observation and Science (EROS) Center (Table 1). The spatial resolution of multi-temporal remotely-sensed Landsat data of the ETM+ and OLI is 30 m. Due to the impact of cloud coverage and other factors, 6 scenes were obtained in this study.

Table 1. List of satellite images.

Acquisition Date	Image Type	Resolution(s)	Bands
11 September 1993	TM	30	7
22 September 1997	TM	30	7
7 September 2003	TM	30	7
20 September 2008	TM	30	7
18 September 2013	OLI+	30	8
8 September 2015	OLI+	30	8

Considering the confluence in the basin, data from meteorological stations (Jiansanjiang, Youyi, Wujiuqi, and Bawusan station) in the upper and middle reaches of the MWNRB were selected to analyze the causes of wetland area change and data from hydrological stations in the upper reaches (Baoqing station) and the outlet section (Caizuizi station) of the Naolihe River Basin were selected to analyze the influence of wetland area change on runoff. The annual precipitation and annual temperature data from Jiansanjiang, Youyi, Wujiuqi, and Bawusan stations (Figure 1) from 1993 to 2015 were obtained from the Meteorological Yearbook of Heilongjiang Agricultural Reclamation. The monthly runoff data from the Baoqing and Caizuizi stations (Figure 1) from 1993 to 2015 were obtained from the Heilongjiang Hydrological Bureau.

2.3. Methods

The visual interpretation method was used to extract swamp meadow wetlands as training samples. The maximum likelihood method, minimum distance method, and neural network method were used to classify land use types from remote sensing images. Among these methods, the maximum likelihood method calculates the maximum likelihood classification t function of each land use category through the training samples, and the land use type corresponding to the classification function with the maximum function value is the classification result [38]. The minimum distance method, based on the statistical feature of each class in the remote sensing image, classifies the pixel to be divided into the class with the smallest distance to the known class [39]. The neural network method, simulating biological neurons with many small processing units, recognizes the land use types in remote sensing images by simulating the human brain with specified algorithms [40].

The Kappa coefficient is used to evaluate the classification accuracy of the three methods. The Kappa coefficient, based on the confusion matrix, is in the range of $[-1, 1]$. The value of the Kappa coefficient is usually greater than 0. The closer the Kappa coefficient is to 1, the higher its corresponding classification accuracy [41].

Based on the classification results of land use types, the areas of different land use types (such as swamp meadow wetland, river wetland, paddy field, and dry field) were calculated. According to the transformation of various land use types in different periods, the influence of human activities (land use) on wetland area change was analyzed.

The M-K variation point test and Theil-Sen trend analysis were used to test the variation point of precipitation and temperature series and calculate the trend of precipitation and temperature before and after the variation point. Combined with the law of wetland area change, the influence of climate change on wetland area change was analyzed. The M-K variation point test determines variation points based on the intersection points of order columns of positive time series and reverse time series [42], and the Theil-Sen trend analysis method calculates the change trend of time series based on the rank sum value of time series [43].

The Gini coefficient and SRI of runoff were used to calculate runoff temporal inhomogeneity. Combined with the law of wetland area change, the influence of wetland area change on runoff regulation ability was revealed. The Gini coefficient, which is between 0 and 1, represents the uniformity of runoff distribution within a year. The closer the Gini coefficient is to 1, the more uneven the runoff distribution within a year [44]. The SRI is calculated based on the variation coefficient of precipitation and runoff, which is used to characterize the runoff regulation ability of the underlying surface. The larger the SRI value, the weaker the runoff regulation ability of the underlying surface [29].

Details of the above methods are given in References [29,38–44], respectively.

3. Results

3.1. Changes and Reasons for the Main Wetland Area of the Naolihe River Basin

3.1.1. Comparison of the Three Classification Methods

The typical region with swamp meadow wetland, river wetland, paddy field, and dry field in the MWNRB are selected (Figure 1). The land use types in the typical region using the remote sensing image and classification method (maximum likelihood method, minimum distance method, and neural network method) are shown in Figure 2. The classification accuracy of the three methods is listed in Table 2.

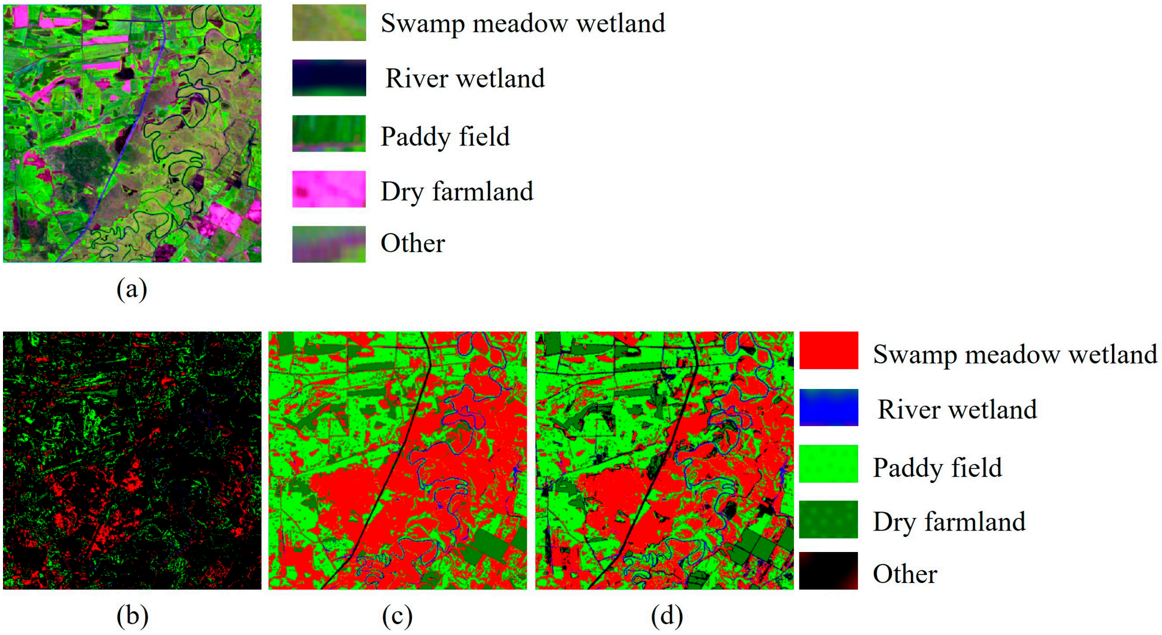

Figure 2. The land use in the typical region by remote sensing image (**a**) and classification method. (**b**) Minimum Distance; (**c**) Neural Net; (**d**) Maximum Likelihood).

Table 2. Kappa coefficients of three classification methods.

Method	Minimum Distance	Neural Net	Maximum Likelihood
Kappa	0.73	0.93	0.94

As shown in Figure 2a, river wetlands in the typical region are linear and noose-shaped, and swamp meadow wetlands are mainly distributed near river wetlands. There are many paddy fields and few dry fields in the typical region. The paddy fields are mainly located in the northwest of the typical region, and the dry fields are scattered in the northwest and southeast corners of the typical region.

Comparing Figure 2a with Figure 2b–d, it can be seen that the minimum distance method has the worst classification accuracy, with a Kappa coefficient of 0.73 (Table 2). The minimum distance method can only identify some swamp meadow wetlands and paddy fields (Figure 2b) and distinguishes most wetlands and paddy fields as other land use types. In addition, it is difficult to identify river wetlands and dry fields in the typical region. The classification accuracy of the neural network classification method with a Kappa coefficient of 0.93 and the maximum likelihood method with a Kappa coefficient of 0.94 is similar (Table 2). Although both the maximum likelihood method and neural network method identify some river wetlands as other land use types (Figure 2c,d), the boundary of each land use type identified by the maximum likelihood method (Figure 2d) is clearer than that identified by the neural network method (Figure 2c). Therefore, the land use classification identified by the maximum likelihood method is the final result of land use types.

3.1.2. The Area Changes in the MWNRB

According to the location of the MWNRB and the distribution of the Naolihe River system, the MWNRB is divided into three subregions to show the wetland area change more clearly. Subregion I is located in the Waiqixing River system, subregion II is located in the Naolihe River system, and subregion III is located in the Qixing River system.

The MWNRB in 1993, 1997, 2003, 2008, 2013, and 2015 is shown in Figure 3. The wetland area in certain years above and the trend of wetland area change from 1993 to 2008 and from 2008 to 2015 calculated using the Theil-Sen trend analysis method are shown in Table 3. On the whole, the MWNRB gradually shrank from 1993 to 2008 with 74.5×10^6 m^2/year, and the area of the MWNRB decreased from 2073.8×10^6 m^2 to 1055.6×10^6 m^2 (Table 3). Compared with 1993, the area of the MWNRB decreased by 49.1% in 2008. From 2008 to 2015, the MWNRB gradually expanded, and the area increased from 1055.6×10^6 m^2 to 1241.6×10^6 m^2 with 27.7×10^6 m^2/year. Compared with 2008, the area of the MWNRB increased by 17.6% in 2015. However, the area of the MWNRB in 2015 is still smaller than in 1993. The area of the MWNRB in 2015 was 59.9% of that in 1993 (Table 3).

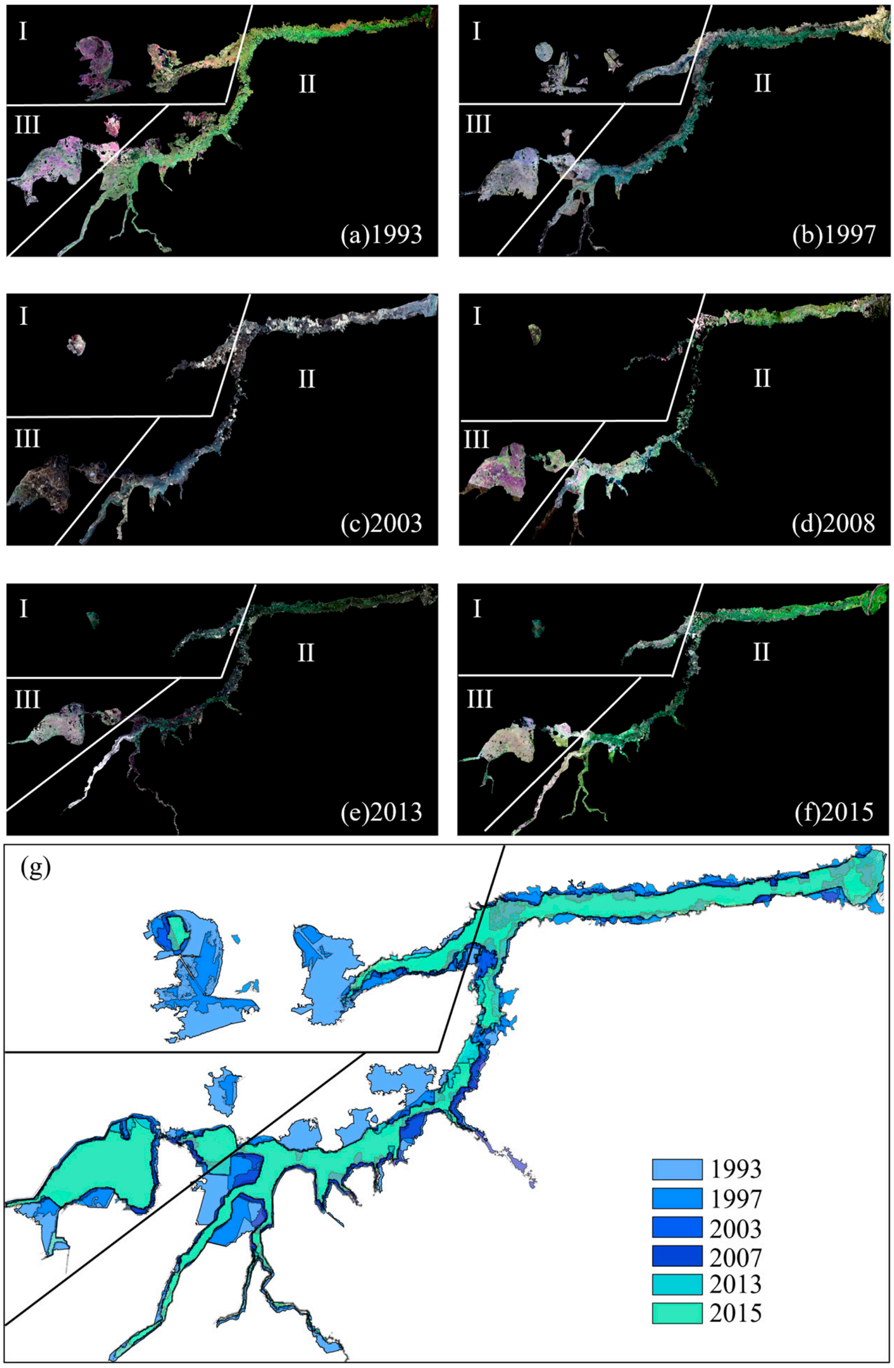

Figure 3. Satellite images of the MWNRB (**a**–**f**) satellite image of the MWNRB in 1993, 1997, 2003, 2008, 2013, and 2015; (**g**) wetland boundary image in 1993, 1997, 2003, 2008, 2013, and 2015.

Table 3. Wetland area in the study area and three subregions from 1993 to 2015.

Area (10^6 m^2) Time	I	Trend (10^6 m^2/Year)	II	Trend (10^6 m^2/Year)	III	Trend	All	Trend (10^6 m^2/Year)
1993	504.0	−32.6	981.2	−30.0	588.6	−14.9	2073.8	−74.5
1997	433.9		930.5		513.7		1878.1	
2003	119.3		650.3		402.0		1171.6	
2008	61.6		621.9		372.1		1055.6	
2013	120.6	11.9	717.6	13.8	378.4	2.0	1216.6	27.7
2015	144.9		709.7		387.0		1241.6	

As shown in Figure 3, the law of wetland area change in the three subregions is similar to that in the whole MWNRB. The area in the three subregions shows a decreasing trend from 1993 to 2008 and an increasing trend from 2008 to 2015. The wetland area change in subregion I is the most significant. As can be seen from Table 3, the wetland areas of the three subregions were the largest in 1993, which were 504.0×10^6 m^2 (subregion I), 981.2×10^6 m^2 (subregion II), and 588.6×10^6 m^2 (subregion III), respectively. The wetland areas of the three subregions were the smallest in 2008, which were 61.6×10^6 m^2 (subregion I), 621.9×10^6 m^2 (subregion II), and 372.1×10^6 m^2 (subregion III), respectively. Compared with 1993, the area of the three subregions in 2008 decreased by 87.8% (subregion I), 36.6% (subregion II), and 49.1% (subregion III), respectively. After 2008, the wetland area of the three subregions increased, and the wetland areas in 2013 and 2015 were similar.

3.2. Reasons for Area Change of the MWNRB

3.2.1. Effects of Climate Change on Area Change of the MWNRB

The variation points of temperature and precipitation series in Jiansanjiang, Youyi, Wujiuqi, and Bawusan stations and the MWNRB are all from 2008. The variation points and the trend before/after the variation point of temperature and precipitation calculated using the M-K variation point test and Theil-Sen trend analysis method are shown in Figures 4 and 5, respectively. As shown in Figure 4, the temperature in Jiansanjiang, Youyi, Wujiuqi, and Bawusan stations and the MWNRB (the average temperature of Jiansanjiang, Youyi, Wujiuqi, Bawusan stations) show a similar trend. The temperature in the four stations and the MWNRB increased in 1993–2008 and 2008–2015. The trend of temperature in 1993–2008, with 0.02–0.06 °C/year, was obviously lower than that in 2008–2015, with 0.06–0.25 °C/year.

As shown in Figure 5, except for the Jiansanjiang station, the precipitation at the Youyi, Wujiuqi, and Bawusan stations and the MWNRB (the average precipitation of Jiansanjiang, Youyi, Wujiuqi, and Bawusan stations) show a similar trend. The precipitation decreased in 1993–2008 and increased in 2008–2015. The trend of precipitation in 1993–2008, with 5.6–8.1 mm/year, was obviously lower than that in 2008–2015, with 16.5–41.2 mm/year.

Based on Figures 3–5 and Table 3, it can be found that from 1993 to 2008, the temperature increased, the precipitation decreased, and the wetland area of the MWNRB decreased significantly. From 2008 to 2015, the temperature and the precipitation increased obviously, and the wetland area of the MWNRB increased. However, the wetland area increase rate from 2008 to 2015, with $2.0 - 27.7 \times 10^6$ m^2/year, was obviously lower than the wetland area decrease rate from 1993 to 2008, with $14.9 - 74.5 \times 10^6$ m^2/year, which indicates that the meteorological factors change in different degrees was not the main influencing factor of wetland area change of the MWNRB. Therefore, the main influencing factor of wetland area change of the MWNRB may be human activities (land use type change). The following will focus on analyzing the impact of human activities on the wetland area change of the MWNRB.

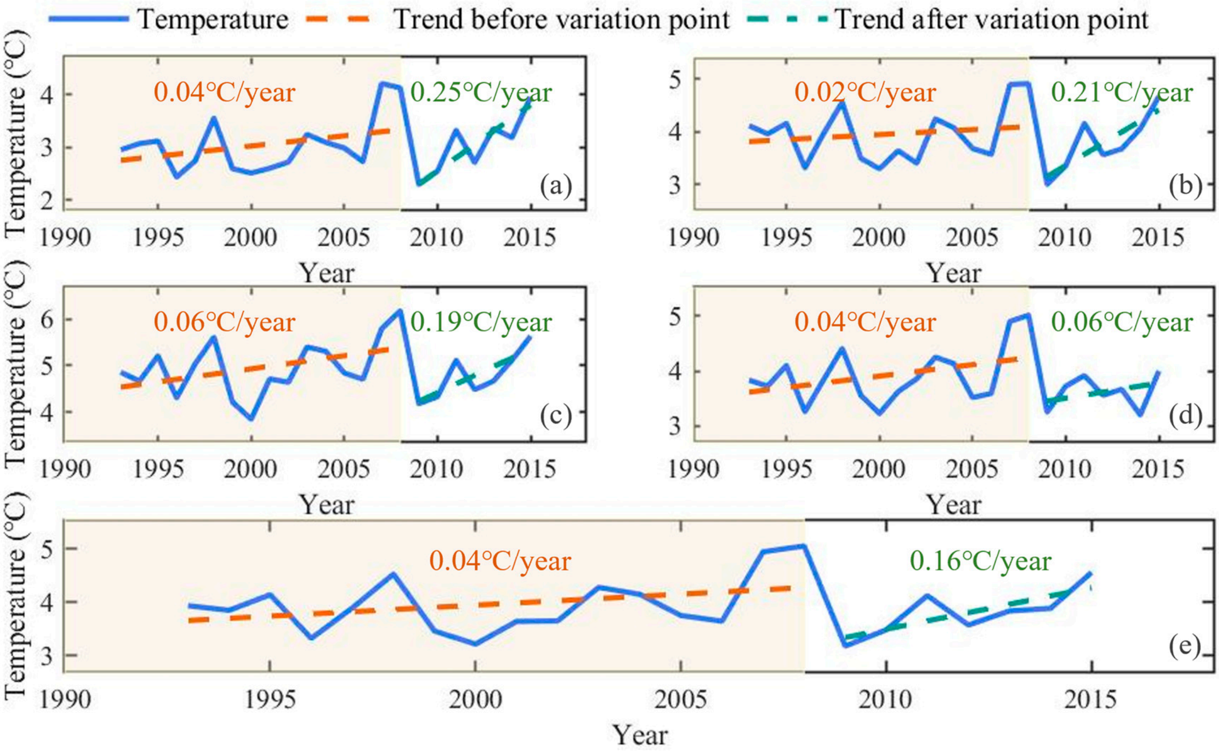

Figure 4. Temperature of the MWNRB from 1993 to 2015 (**a**). Jiansanjiang Station; (**b**). Youyi Station; (**c**). Wujiuqi Station; (**d**). Bawusan Station; (**e**). MWNRB.

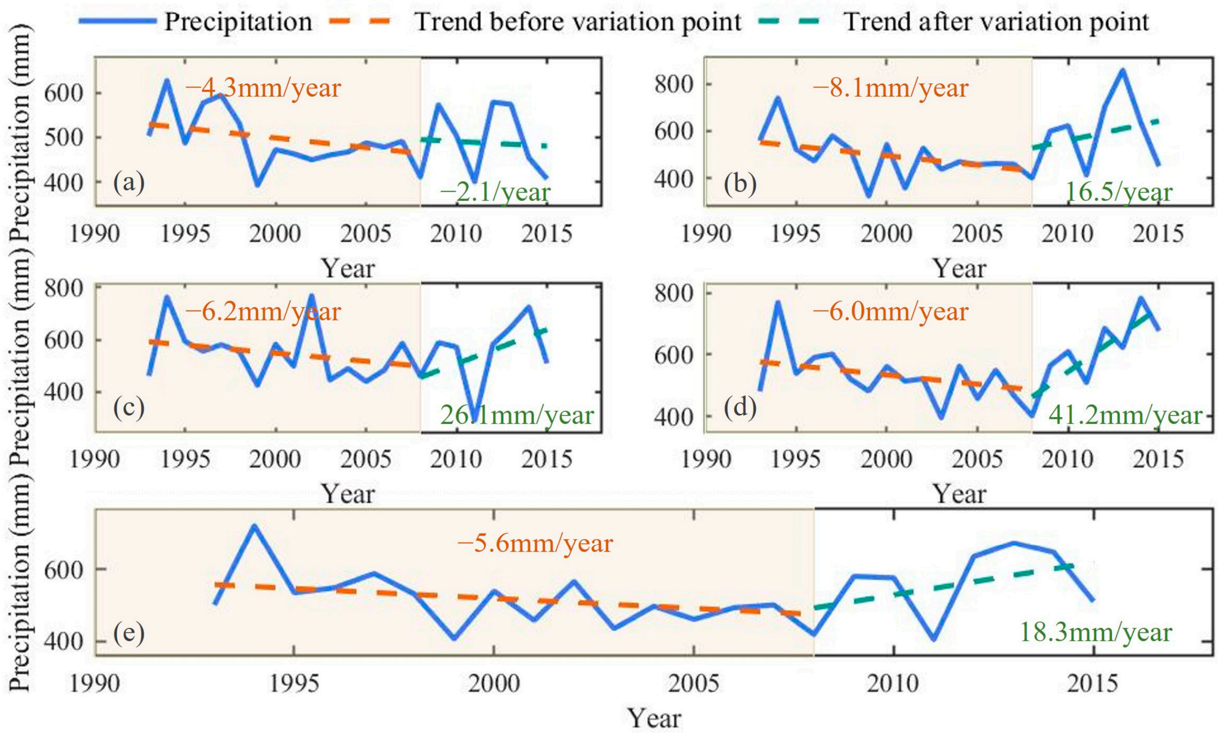

Figure 5. Precipitation in the MWNRB from 1993 to 2015 (**a**). Jiansanjiang Station; (**b**). Youyi Station; (**c**). Wujiuqi Station; (**d**). Bawusan Station; (**e**). MWNRB.

3.2.2. Effects of Human Activities on Wetland Area

From Figure 3 and Table 3, it can be seen that the wetland area in subregion I of the MWNRB changes most obviously, and the five land use types in the MWNRB are all in subregion I. Therefore, the land use change based on subregion I is used to study the impact of human activities on wetland area change. The land use change of subregion I from 1993 to 2015 is shown in Figure 6. There are 5 types of land use in subregion I, which are swamp meadow wetland, river wetland, paddy field, dry field, and other types. In 1993 and 1997, subregion I was dominated by swamp meadow wetlands. After 2008, subregion I was dominated by paddy fields and dry fields.

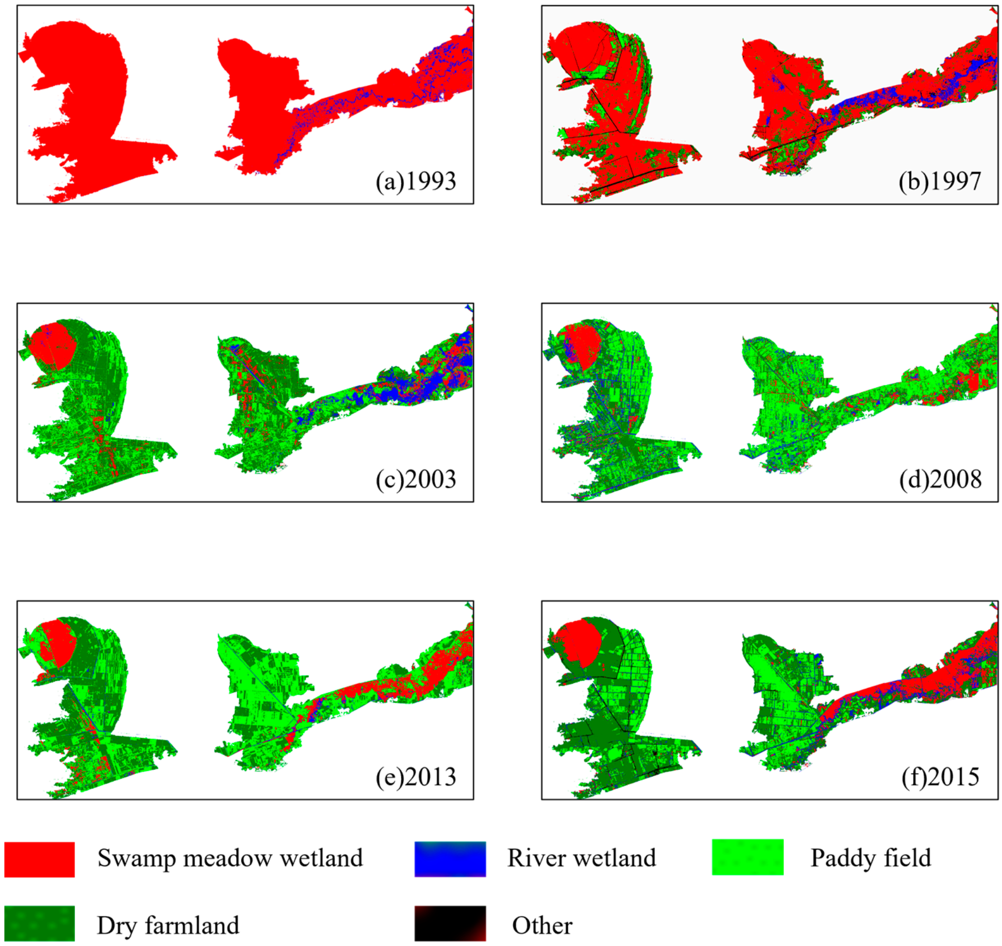

Figure 6. Land use change in 1993, 1997, 2003, 2008, 2013, and 2015 in subregion I.

Figure 7 shows the transformation process between the main land use types in the MWNRB at the main time nodes from 1993 to 2015. It can be seen that from 1993 to 1997, 22.9×10^6 m^2 (5.0%) and 34.8×10^6 m^2 (7.75%) swamp meadow wetlands were transformed into paddy fields and dry fields, and 12.2×10^6 m^2 (24.4%) river wetlands were transformed into other land use types. During 1997–2003, 173.3×10^6 m^2 (43.7%), 141.7×10^6 m^2 (35.8%), and 11.9×10^6 m^2 (3.0%) swamp meadow wetlands were transformed into paddy fields, dry fields, and river wetlands, respectively. From 2003 to 2008, 34.2×10^6 m^2 (49.1%) swamp meadow wetlands and 5.5×10^6 m^2 (11.1%) river wetlands were transformed into paddy fields, and 18.0×10^6 m^2 (36.3%) river wetlands were transformed into other land use types. From 2008 to 2013, 49.4×10^6 m^2 (18.1%) and 9.3×10^6 m^2 (6.7%) paddy fields and dry fields were transformed into swamp meadow wetlands. From 2013 to 2015, 24.5×10^6 m^2 (14.3%) paddy fields were transformed into swamp meadow wetlands.

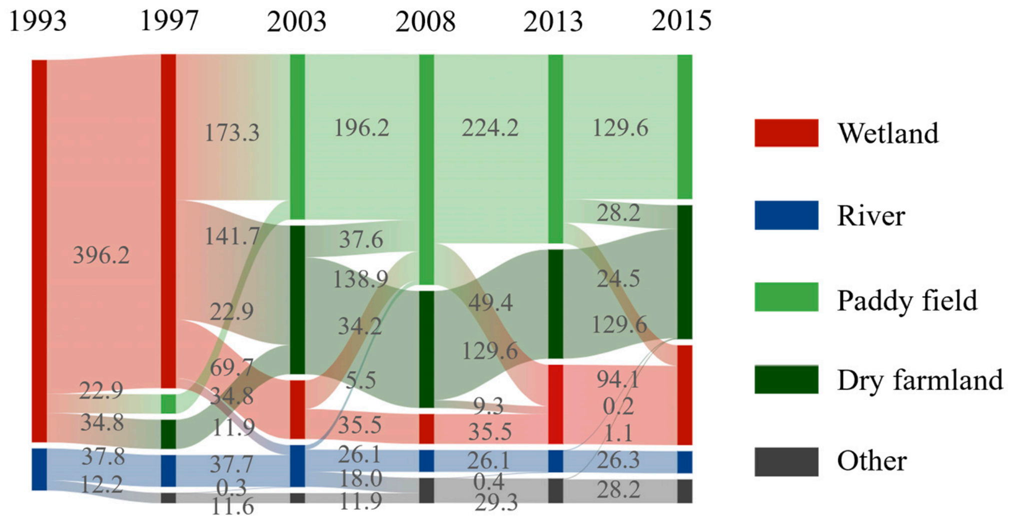

Figure 7. Sankey map of land use area change in subregion I of the MWNRB.

To sum up, the wetland area changes in the MWNRB from 1993 to 2015 can be roughly divided into two stages. The first stage was from 1993 to 2008, during which wetlands were transformed into paddy fields (50.74%) and dry fields (38.87%). The agricultural development aggravates the shrinkage of wetland areas. The second stage was from 2008 to 2015. Due to the implementation of wetland protection and restoration policies, some paddy fields and dry fields were restored to wetlands (61.69% and 7.76%, respectively). However, the wetland area was not restored to the wetland area in 1993. Combined with the wetland area changes in the MWNRB shown in Figure 4, compared with climate change, it shows that land use change caused by human activities is the main reason for the wetland area changes in the MWNRB.

3.3. The Effect of Wetland Area Changes on Runoff

3.3.1. The Effect of Wetland Area Changes on the Uniformity of Runoff Distribution within a Year

The Gini coefficient from 1993 to 2015, the variation point of the Gini coefficient series, and the trend before/after the variation point are shown in Figure 8. As shown in Figure 8, the variation point of the Gini coefficient series is 2008. The Gini coefficient of Baoqing Station is in the range of 0.29 to 0.82, and the Gini coefficient of Caizuizi Station is in the range of 0.22 to 0.67. The Gini coefficient of Baoqing Station is obviously higher than that of Caizuizi Station, which indicates that the runoff uniformity of Caizuizi Station is higher than that of Baoqing Station. Combined with Figure 1, there is no wetland in the upper reaches of Baoqing Station, and the MWNRB is distributed between Baoqing Station and Caizuizi Station, which shows that the existence of the MWNRB regulates the runoff distribution within a year and enhances the runoff regulation ability.

As shown in Figure 8, from 1993 to 2008, the Gini coefficient of Caizuizi Station increased by 0.002/year, while from 2008 to 2015, the Gini coefficient of Caizuizi Station decreased by 0.05/year. Combined with Figure 3 and Table 3, the area of the MWNRB decreased from 1993 to 2008, and the runoff regulation ability decreased, which led to an increase in the Gini coefficient to a certain extent. From 2008 to 2015, the area of the MWNRB increased, and the runoff regulation ability increased, which led to a decrease in the Gini coefficient to a certain extent (Figure 8).

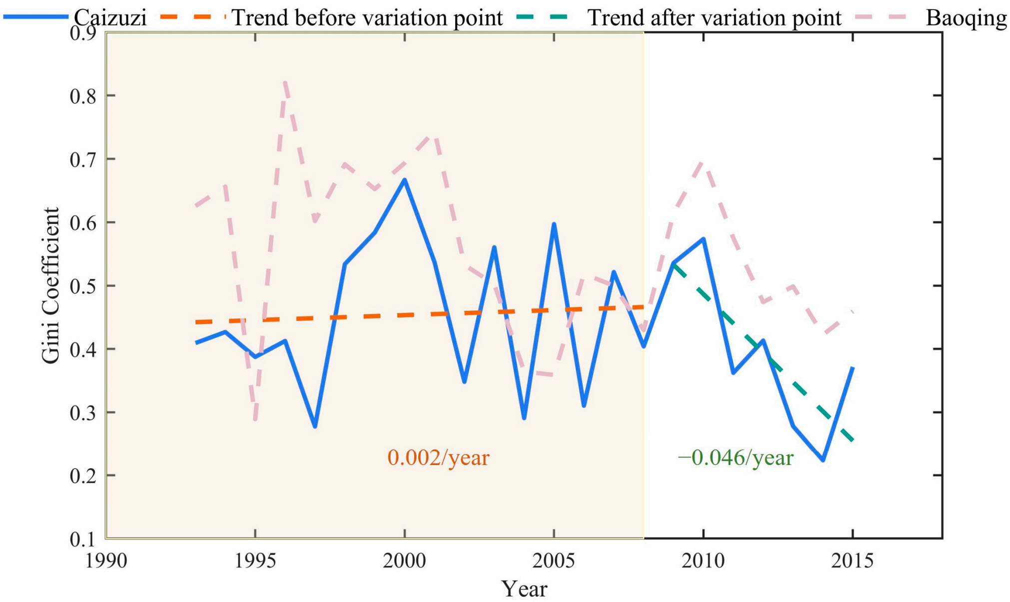

Figure 8. The Gini coefficient of Baoqing Station and Caizuizi Station.

3.3.2. The Effect of Wetland Area Changes on Runoff Regulation Ability

To further reveal the impact of the MWNRB area change on annual runoff, SRI, the variation point of the SRI series, and the trend before/after the variation point were calculated, as shown in Figure 9. The variation points of the SRI series in Jiansanjiang, Youyi, Wujiuqi, and Bawusan stations are all from 2008. The SRI coefficients of the four stations showed similar variation characteristics. From 1993 to 2008, the SRI showed an increased trend of 0.008 to 0.023/year. From 2008 to 2015, the SRI showed a decreased trend of 0.045 to 0.161/year. Combined with Figure 3 and Table 3, it shows that the area of the MWNRB decreased, the runoff regulation capacity weakened, and SRI increased from 1993 to 2008. The area of the MWNRB increased, the runoff regulation capacity increased, and SRI decreased from 2008 to 2015.

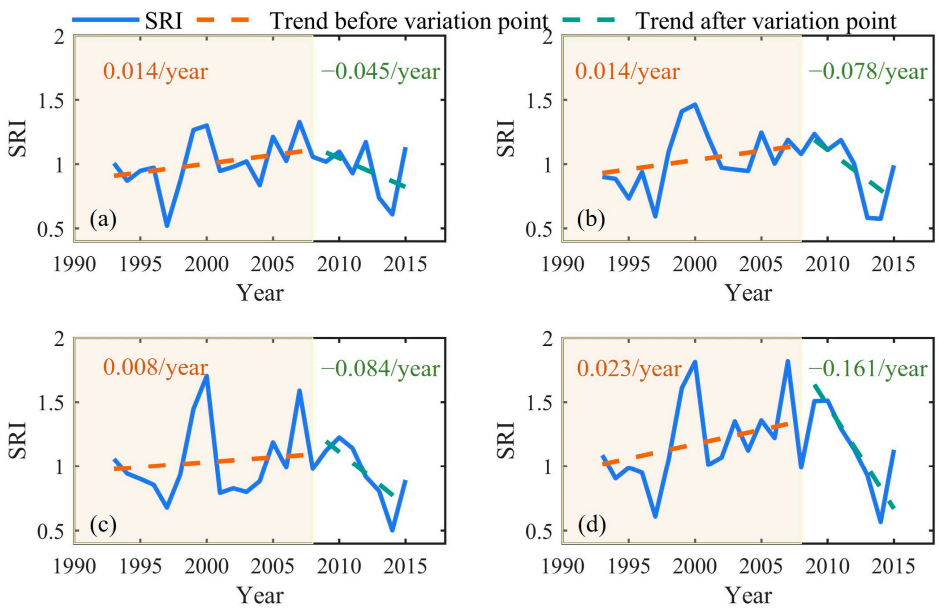

Figure 9. The SRI coefficient from 1993 to 2015 of (**a**) Jiananjiang Station; (**b**) Youyi Station; (**c**) Wujiuqi Station; (**d**) Bawusan Station.

4. Discussion

In this study, the change in precipitation and temperature was used to reflect climate change, and the change in land use area was used to represent human activities. Comparing climate change, human activities, and wetland area change, the causes of wetland area change were analyzed. The result shows that human activities (mainly reclaiming farmland) are the main causes of wetland area change, which is consistent with the conclusion of Liu et al. (2012) [15]. In addition, Liu et al. (2015) and Zan et al. (2020) reached the same conclusion in the semi-arid area of Northeast China and the Amu Darya River Delta, respectively, indicating that human activities are the main reason for wetland area change, which may be a common conclusion [10,45].

Ahmed (2016) and Fossey et al. (2016) found that wetlands provide important hydrological services, including reducing flood peaks, regulating runoff processes, and influencing other changes in hydrological processes [46,47]. To clarify the influence of wetland areas on runoff, the Gini coefficient and SRI index of the Naolihe River Basin from 1993 to 2015 were calculated. The result shows the Gini coefficient increased (decreased) with the decrease (increase) in the wetland area, indicating that the wetland area decreases (increases), the uneven distribution of runoff increases (decreases), and the runoff process concentrates (disperses). Similar to the Gini coefficient, the SRI index of the Naolihe River Basin increases (decreases) with the decrease (increase) in the wetland area, indicating that the wetland area decreases (increases) and runoff regulation capacity weakens (enhances). The results of this study are consistent with those of Walters et al. (2016) [48].

According to the results of this study and other similar studies, human activities in wetlands, especially reclaiming farmland, should be reduced to maintain the regulation of wetlands on runoff.

5. Conclusions

In this paper, based on temperature and precipitation data, maximum likelihood method, minimum distance method, and neural network method, The area changes in the MWNRB and its reasons were explored. The effects of area changes in the MWNRB on runoff were also discussed. The main conclusions are as follows.

(1) Among the three classification methods, the maximum likelihood method is the best, followed by the neural network method. The minimum distance method is the worst.

(2) From 1993 to 2008, the area of the MWNRB and the three subregions decreased significantly, with $14.9 - 74.5 \times 10^6$ m^2/year. From 2008 to 2015, the area of the MWNRB and the three subregions increased by $2.0 - 27.7 \times 10^6$ m^2/year. The area of the MWNRB and the three subregions in 2015 were all smaller than in 1993.

(3) The temperature of the MWNRB both increased in 1993–2008 and 2008–2015, while the precipitation of the MWNRB decreased in 1993–2008, with 4.3–8.1 mm/year, and increased in 2008–2015, with 16.5–41.2 mm/year. The trend of precipitation in 2008–2015 was significantly higher than that in 1993–2008, which is opposite to the trend of area change of the MWNRB in the two stages. It shows that temperature has no obvious influence on wetland area change in the MWNRB, while precipitation has a certain influence on wetland area change in the MWNRB.

(4) From 1993 to 2008, the MWNRB was transformed into paddy fields and dry fields. In 1997, 43.7% and 35.8% of the MWNRB were transformed into paddy fields and dry fields. In 2003, 49.1% and 11.1% of swamp meadow wetlands and river wetlands were transformed into paddy fields. From 2008 to 2015, the paddy fields and dry fields in the MWNRB were partially converted into wetlands. In 2008, 18.1% of paddy fields and 6.7% of dry fields were converted into swamp meadow wetlands, and in 2013, 14.3% of paddy fields were converted into swamp meadow wetlands. Compared with temperature and precipitation, the land use change in the MWNRB is consistent with the wetland area change. The land use change caused by human activities is the main reason for the area change in the MWNRB.

(5) The area change in the MWNRB has a certain influence on runoff. From 1993 to 2008, the wetland area decreased, the Gini coefficient and SRI index of runoff increased, the uniformity of runoff distribution within a year decreased, and the runoff regulation ability decreased. From 2008 to 2015, the wetland area increased, the Gini coefficient and SRI index of runoff decreased, the uniformity of runoff distribution within a year increased, and the runoff regulation ability increased.

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Data Availability Statement: The raw/processed data required to reproduce these findings cannot be shared at this time as the data also form part of an ongoing study.

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