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Impact of Wetland Change on Local Climate in Semi-arid Zone of Northeast China

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Abstract: Wetlands are sensitive to climate change, in the same time, wetlands can influence climate. This study analyzed the spatio-temporal characteristics of wetland change in the semi-arid zone of Northeast China from 1985 to 2010, and investigated the impact of large area of wetland change on local climate. Results showed that the total area of wetlands was on a rise in the study area. Although natural wetlands (marshes, riparians and lakes) decreased, constructed wetlands (rice fields) increased significantly, and the highest increase rate in many places exceeded 30%. Anthropogenic activities are major driving factors for wetland change. Wetland change produced an impact on local climate, mainly on maximum temperature and precipitation during the period of May–September. The increase (or decrease) of wetland area could reduce (or increase) the increment of maximum temperature and the decrement of precipitation. The changes in both maximum temperature and precipitation corresponded with wetland change in spatial distribution. Wetland change played a more important role in moderating local climate compared to the contribution of woodland and grassland changes in the study area. Cold-humid effect of wetlands was main way to moderating local climate as well as alleviating climatic warming and drying in the study area, and heterogeneity of underlying surface broadened the cold-humid effect of wetlands.

Keywords: wetland change; local climate; rice field; semi-arid zone; Northeast China

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1 Introduction

Over the past decades, natural wetlands all over the world have experienced intensive destruction, while constructed wetlands have increased significantly (Niu *et al*., 2012). This change brought about decrease of landscape diversity and increase of fragmentation, thereby resulting in changes in ecological function of wetlands (Costanza *et al*., 1998; Chen and Lu, 2003). The wetland change from natural or anthropogenic impacts and resultantly environment effects have been a global focus in recent years (Lu and Jiang, 2004). Wetlands are ecologically sensitive to climate change (Turner *et al*., 2000), and the composition, structure, distribution and function are correlated to climatic factors (Burkett and Kulser, 2000; Lahmer *et al*., 2001). So, wetlands were significantly affected by global climate change (Larson, 1995; Fu and Li, 2001).

In the same time, wetland changes have produced an impact on climate change at different space scales (Dickenson, 1991; Hostetler, 1991; Pitman, 1991; Hostetler *et al*., 1993; Gorham, 1995; Lofgren, 1997; Chen, 1999). At large and mesoscales, wetlands influence global and regional climate change because carbon storage and emission of wetlands are important factors for global carbon cycle and greenhouse gas content (Song, 2003; Tong and Zeng, 2006; Hu *et al*., 2009; Yang and Tong, 2011). At a small scale, wetlands play

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an important role in determining local climate primarily because of creating cold-humid effect (Gao *et al*., 2002; Gao *et al*., 2003; Gerhard, 2003; Nie and Wang, 2010). Due to large differences in albedo, heat capacity, roughness, and energy exchange compared to other land-use types, under actions of cold radiation and evapotranspiration, wetlands can reduce temperature and raise humidity in its location (Gordon, 1995; Gong *et al*., 2011).

The results of previous studies indicated that cold-humid effect of wetlands are closely related to factors such as season and wetland area (Yan *et al*., 2001; Gerhard, 2003; Zhang *et al*., 2004; Yao *et al*., 2010). The result from Gordon (1995) showed that in July, local temperature decreased by 2℃–3℃, latent heat flux increased by 10–45 W/m^2, and sensible heat flux declined by 5–30 W/m^2 in the lake region of Northwest Canada and the Great Lakes of North America compared to regions without water bodies. Hostetler *et al*. (1993) found that in the Pyramid Lake region of Nevada, minimum daily temperature increased, maximum daily temperature decreased, and air humidity increased during summer. In the Sanjiang Plain of Northeast China, thermal balance in underlying surface changed remarkably because of wetland loss, resulting in mean annual temperature increase and total annual precipitation decrease (Zhang *et al*., 2001; Yan *et al*., 2003; Yan *et al*., 2005; Sun and Song, 2008). Yao *et al*. (2010) found that wetland loss had an effect on maximum and minimum temperature, especially on the latter in the Naoli River Vally of Northeast China. The result of Bao *et al*. (2006) showed that local temperature decreased significantly during summer in the Dalai Nur Wetland of Inner Mongolia Autonomous Region, China. Guo *et al*. (2010) found that wetland loss resulted in increasing temperature and reducing precipitation by using Regional Climate Model 3 (RegCM3) in Three- River Headwater Region, China.

In general, existing studies have two imperfections. First, most studies is focused on natural wetlands, and constructed wetlands have not been fully considered. Constructed wetlands are a conducive subject to study change induced by anthropogenic activities and resultantly environmental consequences because change of constructed wetlands have more complex mechanism and characteristics. Secondly, the other imperfection was lacking of effective research methods for studying climate change at local scale (Findell *et al*., 2007; Nie and Wang, 2010; Gong *et al*., 2011). For example, climate model can not accurately represent characteristics of land-cover in a smaller region because of a low resolution, leading to a dissatisfactory simulation result (Zhao and Luo, 1998; Liu *et al*., 2000; Liu *et al*., 2013), and field observation is more suitable for climate change in a very small region. Thus, it would be necessary to develop a feasible method for investigating impact of wetland change on local climate in a typical region. The study results would be useful to wetland protection and improvement of regional environment.

The semi-arid zone of Northeast China is a major concentrated area of wetlands, including marshes, riparians, lakes and rice fields. Since the middle 1980s, the conversion of natural wetlands has become an important phenomenon due to increasing population and developing agriculture in this region. As a result, over the past decades, natural wetlands have been rapidly shrinking, in the same time rice fields have been dramatically expanding. It is needed to study wetland change and its effect on local climate in this region. The objectives of this study are: 1) to analyze the spatio-temporal characteristics of wetland change in the semi-arid zone of Northeast China from 1985 to 2010 based on available land-cover information and remote sensing data; 2) to investigate the impact of wetland change on local climate such as temperature and precipitation; and 3) to explore the causes of wetland change and influence mechanism of wetland change on local climate.

2 Materials and Methods

2.1 Study area

The study area (43°57′–46°46′N, 121°38′–126°22′E) is located in the western part of Jilin Privince, Northeast China (Fig. 1), including Baicheng, Songyuan, Da′an, Taonan, Zhenlai, Changling, Qian Gorlos, Tongyu, Qian′an and Fuyu counties or cities. It is a low alluvial plain of the Songhua and Nenjiang rivers, with a total area of 46 900 km^2. The climate is semi-arid continental monsoon, with mean annual sunshine of 2800–3000 hours and a total radiation ranging from 5100 MJ/m^2 to 5200 MJ/m^2. The mean annual precipitation is 400 mm, and the mean annual evaporation is 1600–2000 mm. The average relative humidity ranges from 60% to 65%, and the frost-free period ranges from 140 d to 160 d. The

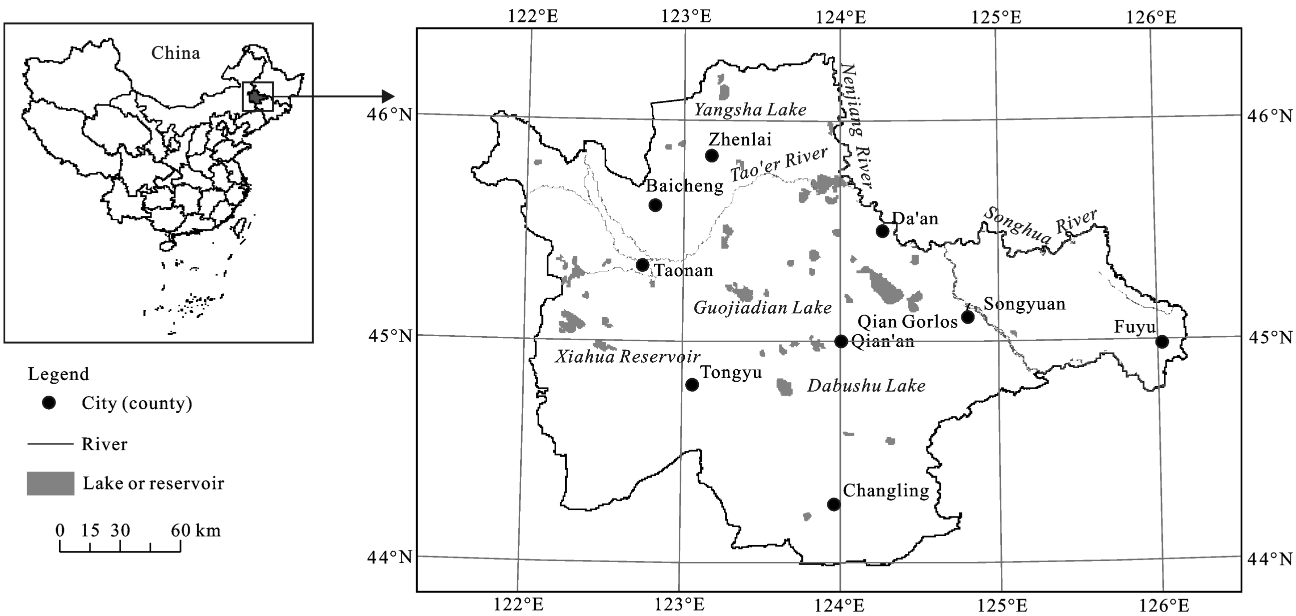

Fig. 1 Location of study area

soil types include Pachic Udic Argiboroll, Pachic Haploboroll, and Typic Haploboroll from east to west. The environment in the study area is ecologically sensitive to human activities. The wetland is a more important land-cover type in influencing ecological environment in the study area than other areas (Wang *et al.*, 2008).

The study area is one of the most productive agriculture regions in China. The main crops include rice, corn, soybean, tobacco, *etc*. The Provincial Government of Jilin implemented 'General Building Plan of Improving Commodity Grain Production Capacity' in 2008, in order to increase grain production. The study area was identified as main area to increase grain production (People's Government of Jilin Province, 2008), and the area of rice fields was predicted to increase by 3000 km^2. As a result, the change in land-use type will alter the quantity and spatial distribution of wetlands in the study area, consequently, the local climate might be influenced.

2.2 Data source and processing

Data on wetland change and land-use types in the study area were acquired from historical land-cover information and remote sensing image of 1985, 1995, 2000, 2005, and 2010. First, geo-rectified and intensified images were used to establish interpretation marks. And then, global positioning system (GPS) was applied for field observation and correction. Finally, the land-use maps of the above-mentioned five periods were generated. With reference to land-use/land-cover (LUCC) classification system in International Geosphere-Biosphere Program (IGBP), land-use maps showed nine land-use types: 1) woodland, 2) grassland, 3) riparian and lake, 4) residential land, 5) rice field, 6) dry field, 7) sandy land, 8) saline land, and 9) marsh. The accuracies of land-use maps all exceeded 90% by field observation, and could meet the need of this study.

Daily meteorological data during May–September were collected to investigate the impact of wetland change on local climate, because the period of May–September is growing season for crops and plants when vigorous evapotranspiration have a significant impact on local climate in Northeast China. The data used in this study (1961–2013, 0.5° × 0.5°) was acquired from the Chinese Meteorological Data Sharing Service System (http://cdc.cma.gov.cn). The socioeconomic data, including total population, value of agricultural output were obtained from *Statistical Yearbooks of Jilin Province* (Jilin Statistical Bureau, 1986–2011) to analyze the causes for wetland change.

2.3 Methods

Change rate of wetland was used to analyze spatio-temporal change of wetland during 1985–2010 in the study area. In this study, ArcGIS(9.3) was used to generate maps of wetland distribution in 1985 and 2010, and grid diagram of 0.5° × 0.5° of the study area (matching the meteorological grid data) (Fig. 2). And then, combining the grid diagram with the map of wetland distribution in 2010, wetland areas and percentages for each grid (wetland area/grid area × 100%) were calculated. Similar method was used to calculate that in 1985. Finally, change rate of wetland per grid from 1985 to 2010 was obtained by subtracting wetland percentage of 1985 from that of 2010. Kriging interpolation was used to map spatial distribution of change rate of wetland. The Markov analysis method was applied for calculating state transitional matrix of all land-use types so as to analyze wetland transformation. The wetland types involved in this study included natural wetlands (marshes, riparians and lakes) and constructed wetlands (rice fields).

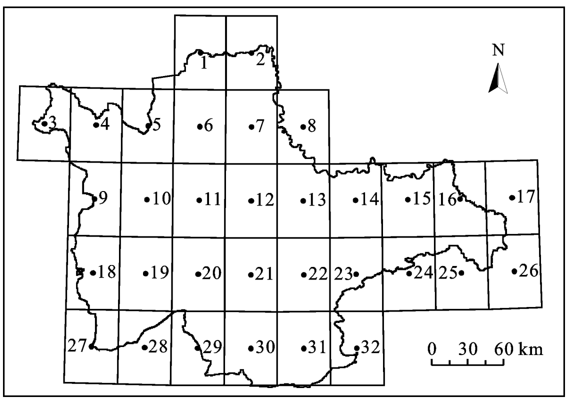

Fig. 2 Grid diagram and code of study area

Tendency rates of temperature and precipitation are used to analyze relationship between wetland change and climate change. In order to acquire them, least-square method was performed to work out linear regression equation of the sample

$$\hat{X}_t = at + b \tag{1}$$

where $\hat{X}_t$ represents temperature or precipitation of sample at time t; a represents tendency rate of temperature or tendency rate of precipitation; and b is a constant.

Maximum temperature, minimum temperature, mean temperature, and precipitation of the study area were selected as the factors to analyze climate change. Tendency rates of above four factors per grid during May–September from 1980 to 2013 were respectively calculated. And, correlation analysis was conducted to select factors significantly correlated to change rate of wetland. Linear regression model were respectively performed between tendency rate of them and change rate of wetland to quantitatively analyze impact of wetland change on local climate. Partial correlation model was used to analyze impacts of wetland change, woodland change, and grassland change on local climate. These statistical analyses were conducted using SPSS 10.0.

3 Results

3.1 Spatio-temporal characteristics of wetland change

As shown in Fig. 3, total area of wetlands in the study area increased by 1674 km^2 during 1985–2010, with a change rate of 24.41%, which attributed to the growth of rice fields. The area of rice fields significantly increased by 3523 km^2, and the area in 2010 was about 4.8 times that in 1985. From 1985 to 2005, rice fields increased steadily, with an increase rate of 103 km^2/yr, while after 2005 it accelerated, with an increase rate of 291 km^2/yr. Natural wetlands showed different change characteristics. In 1985, the area of natural wetlands (marshes, riparians, lakes) is 5929 km^2, occupying about 86% of the total area. However, by 2010, natural wetlands had decreased to 4080 km^2, with a decrease rate of 62 km^2/yr.

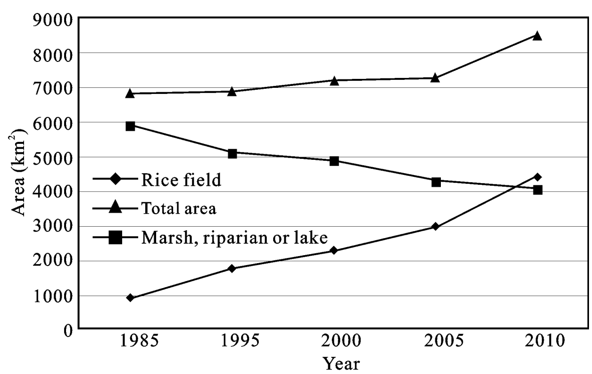

Fig. 3 Change of wetland area from 1985 to 2010 in study area

The spatial distribution of wetlands in the study area was shown in Fig. 4. In 1985, natural wetlands mainly concentrated along the Songhua River and the Tao′er River. In addition, a small quantity of natural wetlands scattered in the study area. By 2010, the distribution of natural wetlands had shrunk. In the same time, the distribution of rice fields expanded gradually, and rice fields were intensively distributed in the mid-eastern, northern, and western parts of the study area.

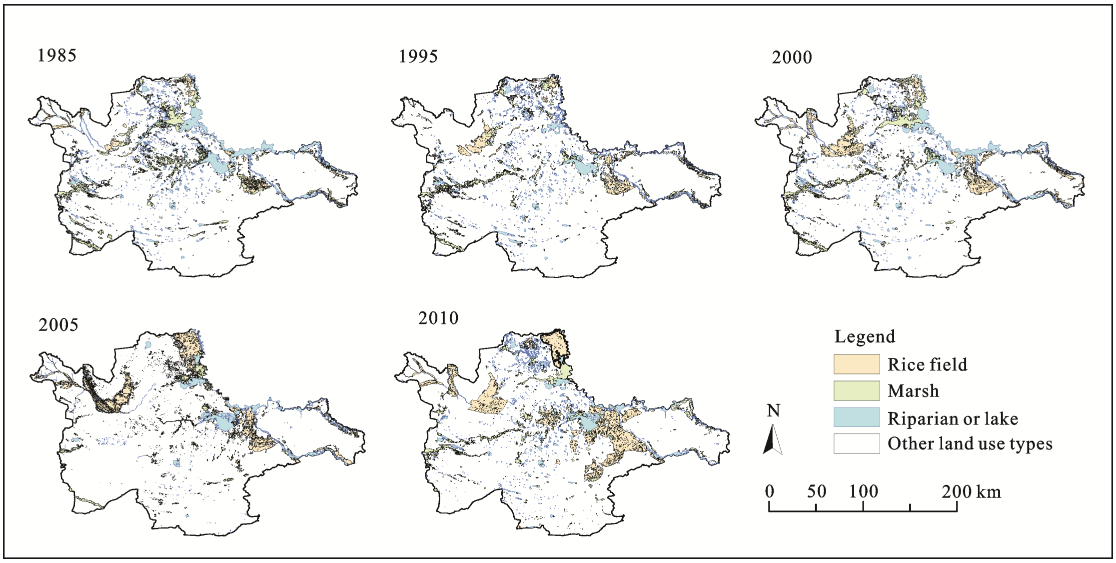

Fig. 4 Spatial distribution of wetlands in study area from 1985 to 2010

The spatial distribution of the change rate of wetland in the study area was shown in Fig. 5. From 1985 to 2010, the change rates of wetland were negative in the mid-southern part, southwestern and southeastern edges of the study area, showing a significant decrease. The decrease rates in some places reached nearly –70%, mainly because massive natural wetlands were transformed into grasslands, saline lands, and dry fields (Fig. 6). The change rates of wetland were positive in the mid-eastern, northern, and northwestern parts of the study area, showing wetland area kept growing. Especially in Qian Gorlos Mongolian Autonomous County, the increase rate of wetland exceeded 30%, mainly because of massive dry fields, saline lands, and grasslands were transformed into rice fields (Fig. 6).

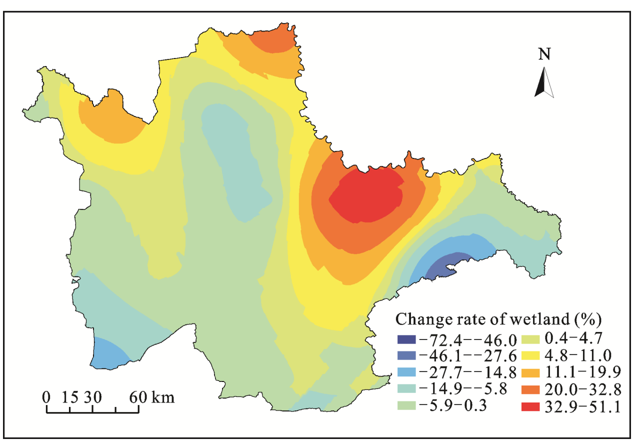

Fig. 5 Spatial distribution of change rate of wetland in study area from 1985 to 2010

State transition matrix was derived from Markov analysis method. The results were shown in Table 1 and Table 2. Natural wetlands drastically decreased during 1985–2010, mainly converted into farmlands (including dry fields and rice fields), grasslands and saline lands. It can be found that 34.87% of marshes, 19.52% of riparians and lakes were reclaimed for farmlands, the area being 968.75 km^2 and 614.96 km^2, respectively. Moreover, 19.17% of marshes degenerated into grasslands, and 7.45% of marshes, 6.18% of riparians and lakes changed to saline lands, and the area were 532.76 km^2, 207.07 km^2, and 194.58 km^2, respectively. Dry fields, marshes and grasslands were the main sources for rice fields. The area of rice fields transformed from dry fields was 2279.84 km^2, being about 65% of the increased area, and the area of rice fields transformed from marshes and grasslands were 551.49 km^2 and 514.03 km^2, respectively.

3.2 Impact of wetland change on local climate

3.2.1 Impact on temperature

The tendency rates of maximum temperature, minimum temperature, mean temperature per grid during May–September from 1980 to 2013 were calculated, respectively. Pearson correlation between them and the change rate of wetland were listed in Table 3. Because the tendency rate of maximum temperature significantly correlated with the change rate of wetlands, a linear regression model between them was fitted as Equation (2):

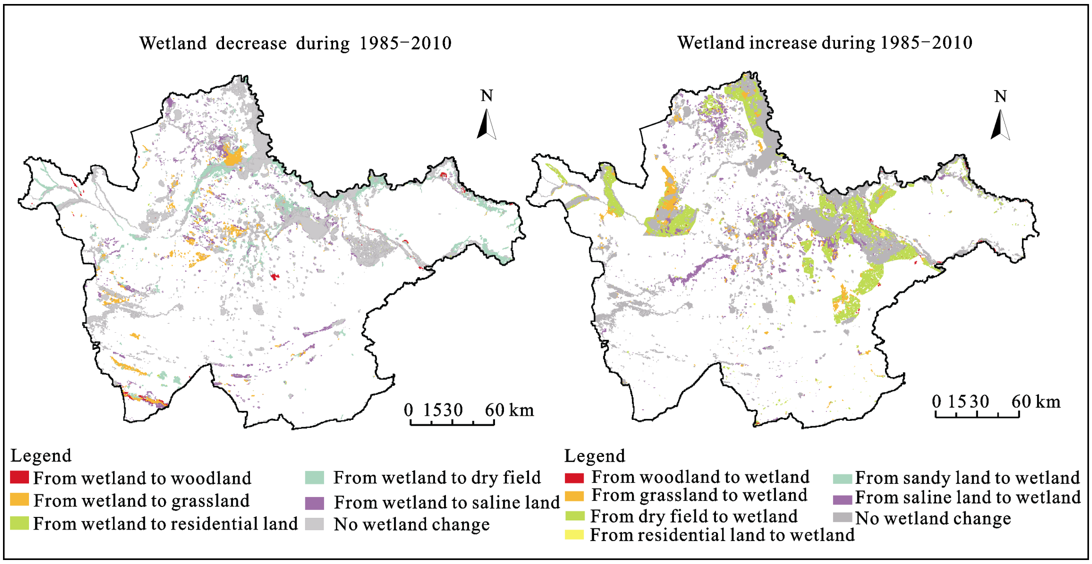

Fig. 6 Spatial distribution of mutual transformation between wetlands and other land-use types

Table 1 State transition matrix of area in all land-use types (km^2)

Land-use type	Woodland	Grassland	Riparian and lake	Residential land	Rice field	Dry field	Sandy land	Saline land	Marsh
Woodland	812.67	35.38	30.18	19.77	30.18	536.92	0.00	19.77	10.41
Grassland	563.98	3106.03	37.46	39.54	514.03	3453.58	43.70	666.99	150.88
Riparian and lake	37.46	75.96	1709.62	52.03	171.69	443.27	0.00	194.58	471.37
Residential land	6.24	9.36	3.12	1376.64	36.42	123.83	0.00	18.73	5.20
Rice field	22.89	1.04	4.16	3.12	691.96	203.95	0.00	4.16	9.36
Dry field	951.06	298.64	94.69	235.16	2279.84	15728.91	1.04	774.17	69.72
Sandy land	74.92	17.69	2.08	3.12	0.00	412.06	100.93	13.53	1.04
Saline land	64.51	887.59	198.74	89.49	188.34	1072.80	3.12	4592.97	223.72
Marsh	45.78	532.76	241.41	5.20	551.49	417.26	0.00	207.07	758.56

Table 2 State transition matrix of change rate in all land-use types (%)

Land-use type	Woodland	Grassland	Riparian and lake	Residential land	Rice field	Dry field	Sandy land	Saline land	Marsh
Woodland	53.87	2.35	2.00	1.31	2.00	35.59	0.00	1.31	0.69
Grassland	6.54	35.99	0.43	0.46	5.96	40.02	0.51	7.73	1.75
Riparian and lake	1.19	2.41	54.27	1.65	5.45	14.07	0.00	6.18	14.96
Residential land	0.40	0.60	0.20	87.64	2.32	7.88	0.00	1.19	0.33
Rice field	2.47	0.45	0.45	0.34	74.59	21.98	0.00	0.45	1.01
Dry field	4.66	1.46	0.46	1.15	11.16	77.03	0.01	3.79	0.34
Sandy land	12.17	2.87	0.34	0.51	0.00	66.93	16.40	2.20	0.17
Saline land	0.88	12.16	2.72	1.23	2.58	14.70	0.04	62.94	3.07
Marsh	1.65	19.17	8.69	0.19	19.85	15.02	0.00	7.45	27.30

$$y = 0.052 - 0.00024x \quad (2)$$

where x is the change rate of wetland (1985–2010); y is the tendency rate of maximum temperature (1980–2013).

F-test results showed that the tendency rate of maximum temperature had a significant linear correlation with the change rate of wetland ($F = 7$, $n = 32$, $a = 0.011$). The tendency rate of maximum temperature and the change rate of wetland were negatively significantly correlated, indicating that with increase (or decrease) of wetland area, maximum temperature decreased (or increased). The changes of wetland area had a significant influence on the maximum temperature from May to September in the study area.

Table 3 Pearson correlation between tendency rate of climate factor and change rate of wetland (n = 32)

	Tendency rate		
	Maximum temperature	Minimum temperature	Mean temperature
Pearson correlation	–0.445*	0.268	0.185
Sig. (2-tailed)	0.011	0.139	0.311

Note: *, correlation is significant at the 0.05 level (2-tailed)

Kriging interpolation was used to map the spatial distribution of the tendency rate of maximum temperature in the study area during the period of 1980–2013 because they were significant (a = 0.05) with a normal distribution (Fig. 7a). The tendency rates of maximum temperature from May to September were all positive, indicating an upward tendency, and increasing from east to west in the range of 0.032–0.071℃/yr. The maximum temperature in the eastern and the mid-eastern parts increased less, by 0.035℃/yr on the average, while the maximum temperature in the western and the southwestern parts increased obviously, by 0.066℃/yr on the average. It was also recorded that the tendency rate of maximum temperature corresponded spatially with the change rate of wetland. In the eastern and the mid-eastern parts, maximum temperature increased less, while wetland area dramatically increased. In the western and the southwestern parts, an inverse trend was observed (Fig. 7a, Fig. 5). The above results showed that the change of wetland area significantly affected maximum temperature during May– September, that is, the increase of wetland area could reduce the increment in maximum temperature, and vice versa.

The spatial distribution of the tendency rate of maximum temperature of 1961–1985 was presented in Fig. 7b. During this period, the tendency rate of maximum temperature gradually increased from the south to north, from negative to positive, with minimum value occurring in the southeastern part of the study area and maximum value occurring in the northern part of the study area (Fig. 7b). There existed a significant difference in spatial pattern between 1961–1985 and 1980–2013. The results of previous study showed that the total area of wetlands reduced by 3940 km^2 during 1954–1986, with a dynamic index of 1.83 (Wang *et al.*, 2006). However, this study showed that the total area of wetlands in the study area increased by 1674 km^2 during 1985–2010 (Fig. 3). There were great differences in wetland area between these two periods. This indicated that the difference in wetland change between these two periods resulted in the difference in the tendency rate of maximum temperature (Fig. 7).

From 1985 to 2010, grassland and woodland area had changed significantly in the study area (Table 1). The impact of wetlands, grasslands and woodlands on maximum temperature were compared by using partial correlation analysis (Table 4). The partial correlation coefficient (PCC) between the change rate of wetland and the tendency rate of maximum temperature was most significant (PCC = –0.522, α = 0.003), followed by the change rate of grassland (PCC = –0.329, α = 0.075). The change rate of woodland did not pass test of significance (α = 0.112). It suggested that wetland change played a more important role in affecting maximum temperature compared to grassland and woodland changes did.

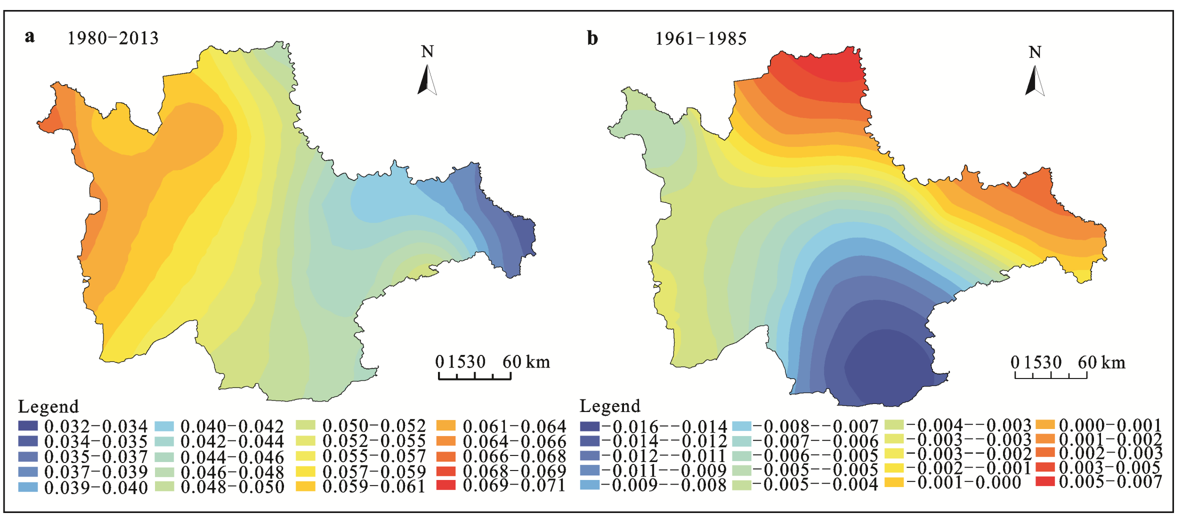

Fig. 7 Spatial distribution of tendency rate of maximum temperature (℃/yr) in study area from May to September

Table 4 Partial correlation coefficient for area change of wetland, grassland and woodland and tendency rate of maximum temperature

Correlated variable	Control variable	PCC	DF	Sig.
Change rate of wetland area	Change rate of grassland and woodland	–0.522	28	0.003
Change rate of grassland area	Change rate of wetland and woodland	–0.329	28	0.075
Change rate of woodland area	Change rate of wetland and grassland	0.296	28	0.112

Notes: PCC, partial correlation coefficient; DF, degree of freedom; Sig., significance level

3.2.2 Impact on precipitation

The tendency rates of precipitation per grid during 1980–2013 were calculated. Due to significant correlation between the tendency rate of precipitation and the change rate of wetland, a linear regression model was set, this linear regression model passed F-test (F = 8.346, n = 32, α = 0.007), and it can be expressed as:

$$y = -2.897 + 0.017x \quad (3)$$

where x is the change rate of wetland (1985–2010); y is the tendency rate of precipitation (1980–2013).

The tendency rate of precipitation and the change rate of wetland was positively correlated, indicating that with increase (or decrease) of wetland area, precipitation increased (or decreased). The changes in wetland area had a significant impact on the precipitation from May to September in the study area.

Kriging interpolation was used to map the spatial distribution of the tendency rate of precipitation in the study area (Fig. 8a). The tendency rates of precipitation from May to September during 1980–2013 were all negative, indicating a downward trend. The decrement in precipitation increased from the east to west with the range from –1.52 mm/yr to –4.24 mm/yr. In the eastern and mid-eastern parts, the decrement in precipitation was lower, with an average of –1.87 mm/yr, while in the western and southwestern parts, the decrement in precipitation was higher, with an average of –3.97 mm/yr. It was also recorded that the tendency rate of precipitation corresponded spatially with the change rate of wetland. In the mid-eastern part, wetland area significantly increased, with a lower decrement in precipitation, while an inverse trend was observed in the western and the mid-western parts (Fig. 8a, Fig. 5). The above results showed that the change of wetland area significantly affected the precipitation from May to September, that is, the increase of wetland area reduced the decrement in precipitation, and vice versa.

The spatial distribution of tendency rate of precipitation during 1961–1985 was presented in Fig. 8b. During this period, in the eastern, southeastern, and western edges of the study area, the decrement in precipitation was lower, with an average of –0.21 mm/yr, while in the northern and southwestern parts, the decrement in precipitation was higher, with an average of –1.39 mm/yr.

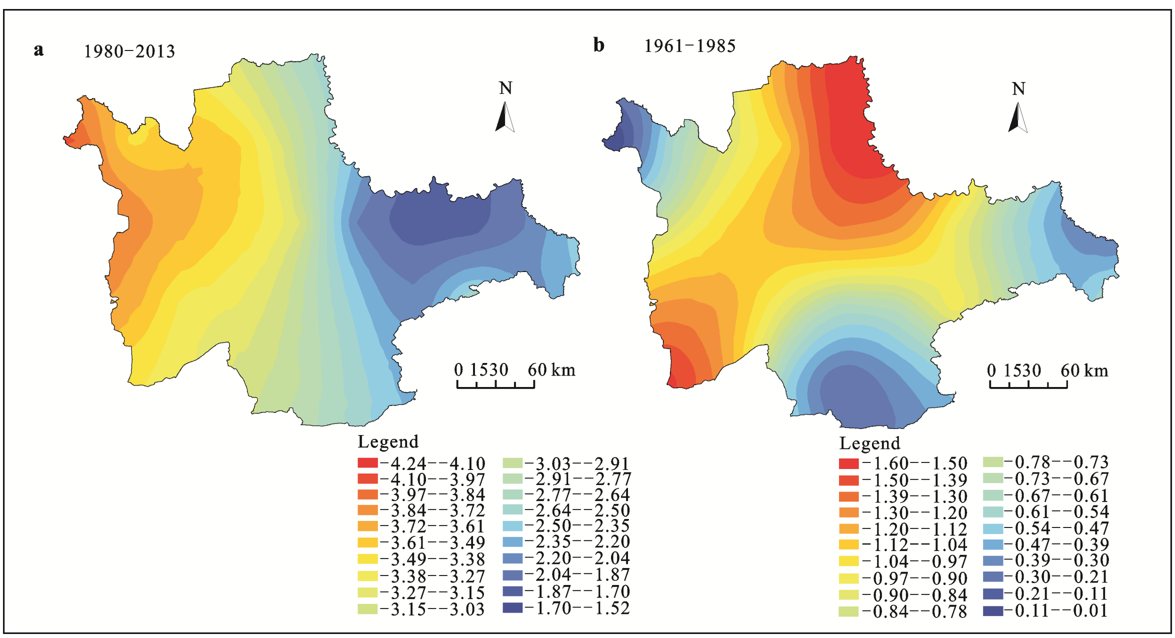

Fig. 8 Spatial distribution of tendency rate of precipitation (mm/yr) in study area from May to September

There existed a significant difference in spatial pattern between 1961–1985 and 1980–2013. In view of obvious difference in wetland change between the two periods (Wang *et al*., 2006) (Fig. 3), it could be concluded that wetland change resulted in the difference in the tendency rate of precipitation.

The impact of wetland, grassland and woodland changes on precipitation was compared by using partial correlation analysis (Table 5). The PCC between the change rate of wetland and the tendency rate of precipitation was higher (PCC = 0.562, α = 0.001), followed by the change rate of grassland (PCC = 0.308, α = 0.059). The change rate of woodland did not pass test of significance (α = 0.178). This confirmed that change of wetland area was a major factor influencing precipitation compared with changes of grassland and woodland did.

4 Discussion

4.1 Causes of wetland change

Wetland change in the study area was determined by interaction of natural and anthropogenic factors. Because of longer time scale of change in natural environment, the influence of anthropogenic factors on wetland change was relatively more profound and significant.

First, the decrease of natural wetlands was attributed to increasing population and massive farmland development in the study area. The rapid growth of population has increased the demand for grain, which turned natural wetlands into farmlands through ditching, draining, tilling, and planting. The total population of the study area increased from 3.8×10^6 to 4.9×10^6 during 1985–2010 (Jilin Statistical Bureau, 1986–2011), in the same time, farmlands gradually increased by 5525 km^2.

Table 5 Partial correlation coefficient for area changes of wetland, grassland and woodland and tendency rate of precipitation

Correlated variable	Control variable	PCC	DF	Sig.
Change rate of wetland	Change rate of grassland and woodland	0.562	28	0.001
Change rate of grassland	Change rate of wetland and woodland	0.308	28	0.059
Change rate of woodland	Change rate of wetland and grassland	–0.252	28	0.178

Notes: PCC, partial correlation coefficient; DF, degree of freedom; Sig., significance level

The farmland area transformed from natural wetlands was 1583.71 km^2, accounting for nearly 30% of the increment of farmlands (Table 1). Grain production was developed at the expense of natural wetlands. Similar decrease of natural wetland area resulting from agricultural activities also occurred in the Sanjiang Plain, Northeast China (Liu *et al*., 2004; Wang *et al*., 2011). Many studies have proved that there exists obvious negative correlation between population and natural wetland area (Yue *et al*., 2008; Chen *et al*., 2012; Niu *et al*., 2012).

Secondly, farmer′s quest for economic returns became an important driving factor for increase of rice field area because the economic returns of rice fields are generally higher than that of dry fields (Wu *et al*., 2011). Since the end of the 1970s, the farmers have been engaged independently in agricultural activities and transformed a large area of dry fields into rice fields in order to achieve more profits. At present, a half of the rice fields (2279.84 km^2) were transformed from the dry fields in the study area, accounting for about 65% of the increment of rice fields. The rise of total value of agricultural output was accompanied by the increase of rice filed area. For example, The total value of agricultural output in Qian Gorlos Mongolian Autonomous Country rose from 3.01×10^8 yuan (RMB) to 6.35×10^{10} yuan during the period of 1980–2007 (Jilin Statistical Bureau, 1981–2008), especially accelerated after 2005, presenting an obvious synchronization with the time of rapid increase of rice field area (Fig. 3).

Finally, the change in land-use types in the study area was closely related to economic policy. In recent years, local government implemented ′General Building Plan of Improving Commodity Grain Production Capacity′, in order to increase grain production from 2.5×10^{10} kg to 3.0×10^{10} kg in five years or longer. The study area was identified as the main region to increase grain production. Therefore, the land-use pattern in the study area changed dramatically through a series of projects, such as land arrangement, water diversion, and irrigation district construction, which promoted rice fields to increase considerably.

4.2 Influence mechanism of wetland on local climate

Many factors could influence local climate, and change in underlying surface was considered as a critical factor related to climate change, because each piece of land has individual energy budgets that change with plant colonization (Fu and Li, 2001; Frank *et al*., 2003). After changing the underlying surface, the radiation, thermal balance, and moisture balance in land-atmosphere system also altered, leading to an effect on local climate. As a special type of underlying surface, wetlands provided climate moderating with an important physical foundation because of its water evaporation and plant transpiration (Zhang and Kong, 2013). In recent years, wetland changed intensively in the study area, causing an influence on temperature and precipitation. Influence mechanism mainly lies in the following two aspects.

First, wetlands create a cold-humid effect which could increase humidity and reduce temperature. The formation of cold-humid effect is related to cold radiation and evapotranspiration (Gao *et al*., 2002). Wetlands are filled with puddles perennially or seasonally, and due to a higher heat capacity and a lower energy consumption, characteristics of heat balance in wetlands is evidently different from dry lands (Zhang *et al*., 2001; Jia *et al*., 2010). Usually, in wetland surface, the latent heat flux accounts for about 70% of radiation amount, while the sensible heat flux accounts for only about 20%. The less energy used for heating atmosphere leads to wetland a colder environment compared with surrounding areas. Moreover, wetland vegetation thrives and has a so strong transpiration that air humidity increase over and around wetlands, so wetlands become a moisture field. Under action of cold radiation and evapotranspiration, temperature reduces and humidity increases over and around wetlands.

The strength of cold-humid effect in wetlands is affected by solar radiation and evapotranspiration. In semi-arid zone, wetlands could produce an effect in delaying and moderating maximum temperature in local place (Gerhard, 2003; Nie and Wang, 2010). Due to increasing area, rice fields have become a primary land-use type in the study area. As a special type of wetlands, rice fields have much similarity to natural wetlands in cold-humid effect and released a lot of moisture towards atmosphere during growing seasons. In the study area, with constant solar radiation, evapotranspiration of wetland vegetation gradually increased, air humidity continuously raised, and the energy consumption steadily increased. Until noon and afternoon, cold radiation and evapotranspiration have been the strongest performance, and cold-humid effect is also most significant. It resulted in an obvious decrease and slow increase in maximum temperature over and around wetlands.

Secondly, the formation of thermodynamic circulation and precipitation in local place are affected by physical heterogeneity in underlying surface (Garrett, 1982; Richard, 1984). Heterogeneity in underlying surface has a more significant impact on short-term precipitation in local and adjacent area through influencing temperature, humidity, and wind compared with inheterogeneity in underlying surface (Yan and Richard, 1988). The transition zone between bare soil and vegetation, irrigated and non-irrigated areas is a preferred location for the initiation of moist convection (Mahfouf *et al*., 1987). In semi-arid zone, heterogeneity in underlying surface, under favorable large-scale atmosphere conditions, could result in the increase of convective precipitation (Richard, 1984; Luo, 1992). In the study area, rice fields, dry fields, and other land-use types criss-crossed, forming a heterogeneous underlying surface. The heterogeneity in underlying surface could improve dynamics circle of atmosphere and moisture. Moreover, because the study area was located in semi-arid zone, the cold-humid effect of rice fields caused intensely thermal differences between rice fields and surrounding environment, forming a local thermodynamic circulation. Under suitable atmosphere condition, this thermodynamic circulation could produce and increase precipitation. Therefore, thermal and dynamic effects of wetland ecosystem tend to create convection current, and produce convective precipitation at local and mesoscale in semi-arid zone.

5 Conclusions

The total area of wetlands is on a rise in the study area during the period of 1985–2010. Natural wetlands (marshes, riparians and lakes) gradually decrease because of its transformation into dry fields and rice fields, while constructed wetlands (rice fields) increase significantly, mainly from transformation of dry fields and grasslands, and natural wetlands. Anthropogenic activities, including population increase, farmland development, quest for economic returns, and economic policy are major driving factors for wetland change.

The spatio-temporal change of land-use types alters the underlying surface, which produces an impact on local climate in the study area. Wetland change plays a more important role in moderating local climate compared to changes of woodlands and grasslands do in the study area.

Wetland change produces a great impact on local climate, mainly influences maximum temperature and precipitation from May to September. Both the changes in maximum temperature and precipitation correspond with wetland area change. In the mid-eastern part, wetland area dramatically increases, while the maximum temperature increment and precipitation decrement are all lower. In the western part, wetlands area decreases, while the maximum temperature increment and precipitation decrement are all higher. Wetland area increase could reduce the increment of maximum temperature and the decrement of precipitation, and vice versa.

Wetlands create a cold-humid effect, which is a main way to moderating local climate as well as alleviating climatic warming and drying in the study area. Heterogeneity of underlying surface in the study area broadens the cold-humid effect of wetlands. The heterogeneous underlying surface tend to create convection current, and produce convective precipitation by improving dynamics circle of atmosphere.

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