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Changes of land use/cover and landscape in Zhalong wetland as "red-crowned cranes country", Heilongjiang province, China

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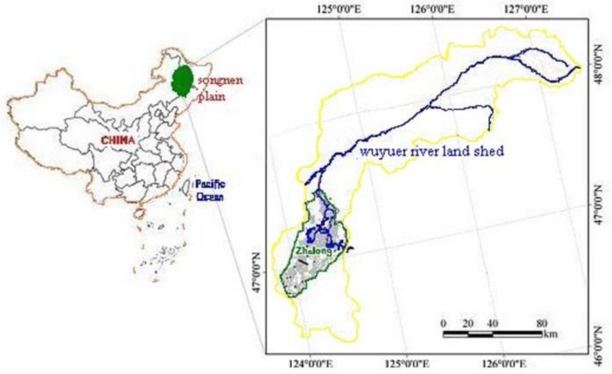
Graphical abstract



Abstract

Hydrological and ecological role of wetlands were growing significant. Based on Landsat satellite remote sensing data collected in the years of 1990, 2000 and 2014, and integrating GIS with analytical methods of landscape ecology, research on changes of land use/cover and landscape pattern of Zhalong wetland from 1990 to 2014 was conducted. Then, we analysed the effect of human activities and climate changes on land use/cover. The main conclusions were as follows: (1) Significant changes in land use/cover have taken place in Zhalong wetland during 1990-2014.Cultivated land, unused land and construction land increased continually, while the area of reed swamp, water swamp, grass land and water land decreased accordingly; (2) Landscape patch shape has be increasingly irregular and turned complexed, there was the tend of the growing diversification and homogenization of land use change and the growing complicate landscape pattern in Zhalong wetland; (3) There was a warm-dry climate trend from 1958 to 2014; (4) Human activities including population, construction, water land pollution and production have been threatening the wetland ecosystem. Those changes in Zhalong area were caused by nature and human activity. However, the human's contributions are great.

Keywords: Climate change, human activities, landscape, Zhalong wetland, land use.

1. Introduction

Wetlands are land areas that are periodically flooded or covered with water land (Owers *et al.*, 2016; Torres Bojorges *et al.*, 2017; Wang *et al.*, 2018). It is the presence of water land at or near the soil surface for more than a few weeks during the growing season that may help to create many wetland conditions (Guo *et al.*, 2004; Liu, 2004; Lyon, 2000; Turner and Meyer, 1994). Zhalong Nature Reserve located in the high latitude areas of Heilongjiang province inland is a world important wetland which is well known for its Red-crowned cranes, is the most important habitat of red Crowned Crane. Red Crowned Crane is the most sensitive and obvious indicator species in wetland environmental changes. However, in recent years, Zhalong's wetlands have been facing increasingly threats from intensified human exploitation and climate change (Ogunkule *et al.*, 2019; Sajil Kumar, 2020; Zhou and Zhang, 2010). The double threats of climate change and human activity lead to drastic changes in the spatial distribution pattern of Red Crowned Crane breeding habitat, which greatly increased the extinction risk of Red Crowned Crane population in Zhalong Nature Reserve. So, studys on the change of ecological environment in Zhalong wetland are very important.

At present, the researches of Zhalong wetland mostly focused on land use, vegetation, soil and hydrology and so on, But, the synthesis studies on land use, landscape and driving force were still weak, in particular, the less studies on the effect of climate changes and human activities on larger scales (Gai *et al.*, 2002; Khatun *et al.*, 2020; Zhang *et al.*, 2010; Zhou *et al.*, 2003; Zou *et al.*, 2003). So, in this paper, land Use/Cover spatial pattern, the combination characteristic and the dynamic will be systematically analysed, the essay maked an overall investigation about the driving factors of human activities and climate change in the past 50 years, the main purpose of this thesis is to explore the double effect of both human activities and climate change on Zhalong wetland, so as to provide science basis for rational planning and decision making for the sustainable development of Zhalong.

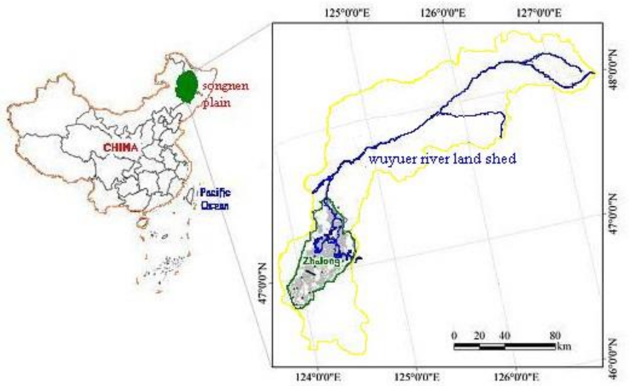


Figure 1. Map of Zhalong wetland, Heilongjiang Province, China, 2014

2. Materials and methods

2.1. Study sites

Being well known for its red-crowned cranes and other kinds of cranes, Zhalong is called as "Crane's Country". There are total 15 kinds of crane in the world, ZNR has 6 of them. The 1/6 of the total world-wide red-crowned crane population comes to Zhalong Reserve (Jegatheesan and Zakaria, 2018; Shoaib *et al.*, 2018; Zhang *et al.*, 2010). Zhalong Nature Reserve (ZNR) is situated within 46°52′-47°32′ N and 123°47′-124°37′ E, and forms an inland delta at the lower reaches of Wuyuer River. Wuyuer River water land shed is located at 46°23′-48°25′ N, 123°47′-127°27′ E, lies in the northeast Songnen Plain, Heilongjiang Province, China (Figure 1). Zhalong wetland was listed as a wetland of international importance in 1992 and forms Zhalong National Natural Reserve (ZNNR). The wetland is a transition zone from the continental subhumid area to the continental subarid region and measures approximately 2,100 km^2. Within the wetland, the main land cover types are reed, sedge, wet meadow, grassland, and cultivated land, and 69 families and 525 species of plant have been reported in this area.

2.2. The remotely sensed images

There remote sensing images (Landsat TM of 10 m × 10 m spatial resolution), for August 13,1990, September 15, 2000 and September 26, 2014 were used to analyze land cover and landscape changes in the Zhalong wetland. All the images were acquired from the vegetation season, which is be suitable for land cover research. Other related indices used in research on land use was as follows:

(1) The adigital district map and topo graphicmaps in 1995 on the scale of 1: 10,000 for Zhalong NNR from the Heilongjiang Mapping and Surveying Bureau. (2) The growing matic map on the scale of 1: 200,000 from the Heilongjiang Geography Institution, Chinese Academy of Sciences in 1995. (3) Meteorological information from 1990 to 2014 from the Heilongjiang Weather Bureau, (4) Runoff data from 1990 to 2014 at two hydrological stations (5) social economic data of statistical year from the Heilongjiang Land Use Bureau.

The three images were analyzed in Erdas Imagine software. There images were geometrically corrected to the TM projection system (Zone 18, meters, NAD 83 datum). Nearest neighbor resampling was used to rectify the images, and resulting RMSE values for each image were under 1 pixel (Liu *et al.*, 2016). Radiometric correction was performed to reduce the effects of different atmospheric conditions on the three dates using a simple linear regression model between the brightness values for several spectrally stable target reflectors at the base time T 1990 and the brightness values of the targets at T 2014 for all bands.

Bands 4, 3 and 2 were used in the classification process as they were particularly useful for wetland discrimination. Signatures for each land cover class (in areas where change was minimal) were gathered in the field using the GPS method described above (Anish and Samata, 2018; Lanjwani *et al.*, 2020; Kumar, 2017). Supervised classification of bands 4, 3, and 2 for each date used a minimum distance classifier yielding 7 classes: cultivated land, reed swamp, water swamp, water land, grass land, unused land, and construction land.

A stratified random sample of ground control for each class was used in an accuracy assessment, and 100 ground control points were visited in the field. Overall accuracy for each date was acceptable–1990 had an overall accuracy of 89 percent, 2000 had an overall accuracy of 87 percent, and 2014 had an overall change in the Zhalong wetland. All the images were acquired from the vegetation season, which is be suitable for accuracy of 88 percent (Li *et al.*, 2017; Rahman and Riad, 2020; Sultana *et al.*, 2019).

2.3. Land use dynamic degree

For comparing land use change, measures such as the dynamic level of the single land cover type were used in the study, the formula is as follows:

$$K = \left(\frac{U_a - U_b}{U_a} \frac{1}{T} \right) \times 100\% \qquad (1)$$

In the equation, K was taken as the dynamic degree of some land use type in the T Period of time, Ua was taken as the area of some land use types at the beginning of research, Ub as the area of it at the end, T as the span of study period (Azeem *et al.*, 2018; Li, 1995).

2.4. The landscape pattern

Landscape pattern in Zhalong NNR under the influence of land use/cover change is a core issue. Six landscape ecology indices commonly were used to analyze the landscape pattern over time in Zhalong NNR including the largest patch index (LPI), landscape shape index (LSI), patch density (PD), number of patches (NP), The landscape diversity index (LDI), The evenness index (EI).

The LPI reflected the connectivity and advantage of wetland landscape, respectively. LSI and PD defined the patch shape complexity and patch boundary connectivity, and NP was an indicator of the level of fragmentation (Liu and Liu, 2010). LDI reflected the types of land use, multi degree and heterogeneity of the patch in every type. EI described the uniformity of different types in land use distribution (Chen *et al.*, 2002; Sofia *et al.*, 2018; Wen *et al.*, 2014).

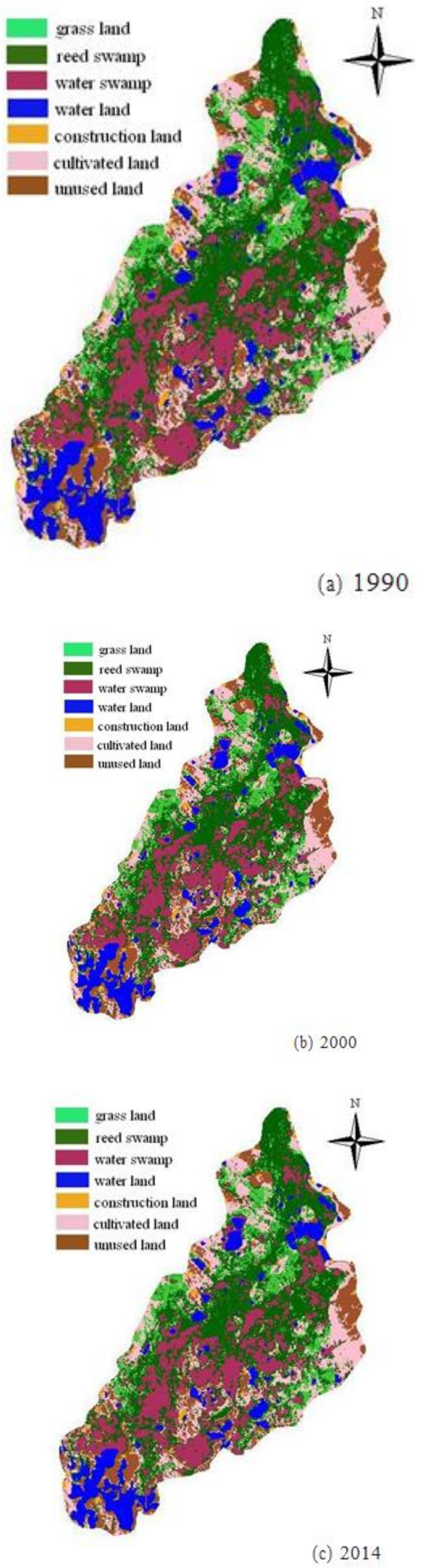


Figure 2. Classification map of land use in Zhalong wetland during 1990-2014

After manually digitized vector GIS images were converted to raster format, various landscape indices were computed to analyze the landscape pattern by Fragstats 3.3.

2.5. Land use types barycenter

The barycenter moving of land cover can be caused by land use changes, the distance and direction of the barycenters drift reflected the degree and trend of marsh landscape changes, respectively, can reveal the spatial variation of land-use types in the study period (Mat Ali *et al.*, 2019; Zhang *et al.*, 2006). Through the model of land use barycenter, the barycenter of each land cover types in Zhalong wetland were computed using RS 9.1, the formula is as follows:

$$X_t = \frac{\sum_{i=1}^{n}(C_{ti} \times X_i)}{\sum_{i=1}^{n} C_{ti}} \qquad (2)$$

$$Y_t = \frac{\sum_{i=1}^{n}(C_{ti} \times Y_i)}{\sum_{i=1}^{n} C_{ti}} \qquad (3)$$

In the equation, X_t Y_t were taken as the barycentric coordinates in Latitude and longitude of some land use types in the year t; C_t was taken as the area of some land use types in the "*i*" smallt region; X_i Y_i were taken as latitude and longitude of the barycentric coordinates in the "*i*" small region.

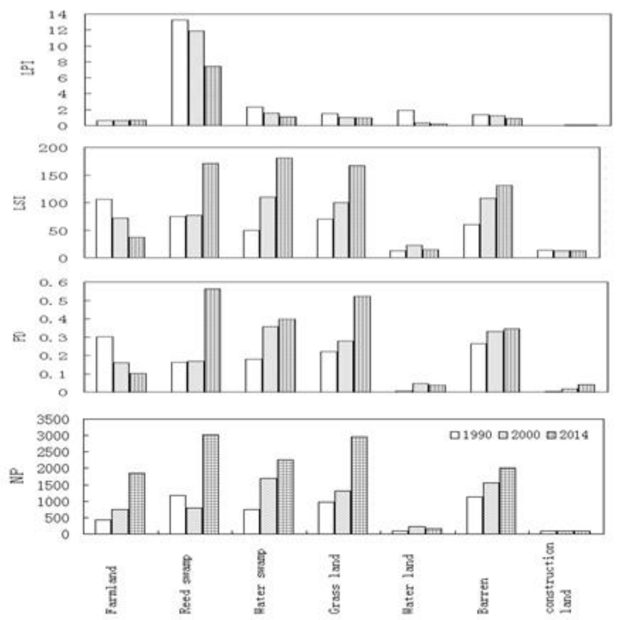


Figure 3. Zhalong landscape pattern change from 1990 to 2014

2.6. Analysis on driving factors

In this paper, reflecting based on cultivated area change, social economic statistics as economic factors, the correlative relationships between land use changes and social economic factors were analyzed by means of factor layer stepwise regression and principal component analysis method (Austin *et al.*, 2018; Verburg *et al.*, 2006).

The main driving factors included three levels: population, agricultural production and rural economy, among them, the population level containing population (x_1) and total households (x_2); the agricultural production level containing area of grain (x_3), effective irrigation area (x_4), electricity in rural areas (x_5) and amount of fertilizer (x_6); the rural economy level containing income of rural residents (x_7), per capita income (x_8), grain output (x_9) and large livestock herd (x_{10}).

2.7. Climate change

Using meteorological information of the closest weather station, Lindian, over the past 55 years, adopting the methods of moving average and trend analysis (Shalmashi and Khodadadi, 2019), based on the time series of temperature and precipitation from 1955 to 2014, the trend of climate change of Zhalong wetland since recent 55 years had been analyzed.

3. Results

3.1. Land use change in Zhalong area

There years (1990, 2010 and 2014) Landsat images and their land cover dynamics were analysed (Figure 2 and Table 1). Among the seven land use types, cultivated land, reed swamp, water swamp, grass land, water land, unused land, construction land have changed drama-tically, cultivated land, unused land and construction land all showed a trend of increasing in prophase (1990-2000) and anaphase (2000-2014), while water swamp and grass land both decreased to varying degrees. In prophase (1990-2000), the increasing range of land area was unused land (0.69%), cultivated land (0.24%), construction land (0.04%) every year, water land, water swamp and grass land declined sharply by the dynamic of 0.05%, 0.17% and 0.06% every year. In prophase (2000-2014), the increasing range of land area was cultivated land (0.32%), unused land (0.18%), construction land (0.13%), water land (0.05%), reed swamp (-0.08%), water swamp (-0.08%), grass land (-0.15%) every year. The percentage of reed swamp was the biggest, secondly for water swamp, grass land was the third in 1990, 2000 and 2014 landsat images (Havrysh *et al.*, 2019), which results showed that swamp and grass land are substrate landscape types of Zhalong wetland, playing the important role in wetland.

3.2. Landscape pattern change in Zhalong wetland

3.2.1. Landscape types level

The analysis on landscape pattern of Zhalong wetland at the landscape types level showed that, LPI and NP of cultivated land were ascending in 1990-2000 and 2000-2014, but LSI and PD of it were on the opposite trend (Figure 3). LPI of reed swamp, water swamp, grass land and unused land all decreased in 1990-2000 and 2000-2014, LSI, PD and NP of them were ascend, LPI of water land was descend in 1990-2000 and 2000-2014, LSI, PD and NP of it were all ascend in 1990-2000 and descend in 2000- 2014, but increased in 1990-2014.

The research on landscape pattern change in Zhalong wetland indicated that, spatial connectedness and landscape dominance of cultivated land and construction land increased gradually, patches of them tended to be more regular. On the contrary, the spatial connectedness and landscape dominance of reed swamp, water swamp grass land and unused land decreased, patches of them were more separated, broken and not more regular than before.

3.2.2. Landscape level

In landscape level, the tendencies of LSI, NP and PD were all ascend in 1990-2000, 2000-2014 and 1990-2014, while LPI was on the contrary. The results showed that the landscape patch shape had be increasingly irregular and turned complexed (Eyankware, 2019; Wang and Li, 2017). The landscape diversity index and the evenness index were descending in 1990-2000, ascend in 2000-2014, and ascend as a whole in 1990-2014, the results indicated, in Zhalong wetland, the growing irregulation in landscape shape, the growing diversification and homogenization and complicate in landscape pattern (Table 2).

3.2.3. Centrobaric migration

The analysis on centrobaric migration of land cover types showed, in lately 20 years, the centrobaric of water land migrated to the southwest, the migration directionin of reed swamp, water swamp, cultivated land, construction land, grass land and unused land were northeast in Zhalong wetland, among them, the farthest migration distance is 184.94 m of grass land, followed by cultivated land (56.96 m).

Table 1. Zhalong land use change from 1990 to 2014.

Land use	1990-2000		2000-2014	
	Area (km^2)	Dynamics (%)	Area (km^2)	Dynamics (%)
Grass land	-24.33	-0.06	-52.70	-0.15
Reed swamp	1.11	0.00	-65.94	-0.08
Water swamp	-75.71	-0.17	-29.52	-0.08
Water land	-81.42	-0.50	4.26	0.05
Construction land	0.90	0.04	3.33	0.13
Cultivated land	49.43	0.24	81.89	0.32
Unused land	130.02	0.69	58.68	0.18

Table 2. Zhalong landscape indices from 1990 to 2014.

Year	LPI	LSI	PD	NP	H	E
1990	12.2981	45.8586	1.1545	4647	1.6699	0.8581
2000	11.8754	69.9063	1.3555	6409	1.6443	0.8450
2014	7.5915	110.3174	2.5540	12340	1.7086	0.8776

Table 3. Principal component load matrix analysis.

Factors	The first principal component	The second principal component
X_1	0.908	0.116
X_2	0.654	0.734
X_3	0.695	0.104
X_4	0.203	0.863
X_5	0.680	0.034
X_6	0.885	0.316
X_7	0.923	0.117
X_8	0.709	0.143
X_9	0.919	0.033
X_{10}	0.003	0.354

Table 4. Principal component contribution rate analysis.

Principal component	Characteristic roots	Variance contribution rate	Cumulative variance contribution rate
The first	5.223	52.229	52.229
The second	1.569	15.692	6.921
The third	1.216	12.160	80.081

3.3. Driving force analysis

3.3.1. Human activities in Zhalong area

Since Zhalong Nature Reserve was established, Zhalong wetlands were managed by a special organization - Management Bureau of Zhalong Nature Reserve, which provides some helpful functions on the planning, management, publicizing and protection of the ZNR. Some steps were very important for the preservation of the wetlands. For instance, hunting was forbidden ten years ago. Water land citing engineering was actualized since 2001, till April 2004, 950 million m^3 has been supplied to ZNR from Nen river by 5 times. The first special water land resources plan focused on wetland preservation: "Planning Report on Water land Resources in Zhalong Wetland" was discussed by Songliao Committee in Cangchun city. However, ZNR still faces a lot of threats of some human activities: Since 1990, more than 60 reservoirs have been built in the up-stream areas for agricultural and other uses, which have resulted in a significant reduction in water land supplies from 680 million m^3 per year to 40 million m^3. The population in ZNR is about 29,000 which is the twice of that in 1979 (Sun, Wang, and Wang, 1997). Though a wetland emigration plan started in 2003. The project is still on the paper but not been implemented. Until now, 21 construction projects have been suspended within the reserve.

Therein to the national highway 301 finished in 2002 goes across ZNR with 29.4 km distance and 30 m width, which severely blocked the water land flow between two sides and brought much noise to the red-crowned cranes and other avifauna (Ilyas *et al.*, 2018; Zhao, 2005). In September 2004, three man-made dykes with a length of 170- 4000 m were dug in the center area of the reserve, which destroyed the structure of wetland formed for hundreds of years (Zhang and Fu, 2007). Tens of millions of wastewater land from industry, agriculture and residence are been drained into the reserve every year (Cui, Zhang, and Li, 2009), the pollution issue has been noticed for more than ten years, but not resolved yet (Li and Lv, 2006).

As results of human activities, Zhalong land use have changed in the way and structure. Due to the growing intensity of human in the way and structure. Due to the growing intensity of human swamp as substrate landscape decreased (Gerami *et al.*, 2017), the patch number, the patch density, landscape variety and landscape evenness index all increased, landscape advantage decreased, Landscape patch shape has been increasingly irregular, Zhalong wetland turned complexed and fragmentation.

The principal component analysis on driving force factors of the cultivated land in Zhalong wetland showed that the characteristic root of three principal components were more than 1, the cumulative variance contribution rate of which reached 80.081%, among them, the first principal component reached 52.229%. The loading factors of income of rural residents (x_7), grain output (x_9) and population (x_1) in the first principal components are more than 0.9, With the exception of effective irrigation area (x_4) and large livestock herd (x_{10}), variable loading factors were all large in the first principal components, the relative importance of which were income of rural residents (x_7), grain output (x_9), population (x_1), amount of fertilizer (x_6), per capita income (x_8), area of grain (x_3), lectricity in rural areas (x_5) and total households (x_2) in turn. It showed that the selected variables played the great driving role in the quantity change of cultivated land (Chen *et al.*, 2017). Among the first principal components, the income of rural residents, grain output and population effected dramatically on the change of cultivated land, so, rural economy and agricultural population were the main influencing factors of the change of cultivated land (Tables 3 and 4).

3.3.2. Climate trend in Zhalong area

In Figure 4, the straight line represents the change trend of the annual and seasonal mean temperature in Zhalong wetland, the kinked line represents the 5 years moving average of its. since recent 50 years, there have been the significant increasing trend for the average temperature in Zhalong wetland, the annual, spring, summer, fall and winter average temperature in Zhalong wetland increased at the rate of 0.44°C·10a^{-1}, 0.58°C·10a^{-1}, 0.27°C·10a^{-1}, 0.30°C·10a^{-1} and 0.59°C·10a^{-1}, among these, it was the best significant increasing trend in winter, the best insignificant in summer, for the temperature rise rate, the former is about 2.6 times of the latter, the temperature rise rate in winter, spring were higher than that of annual, however, summer and fall were opposite.

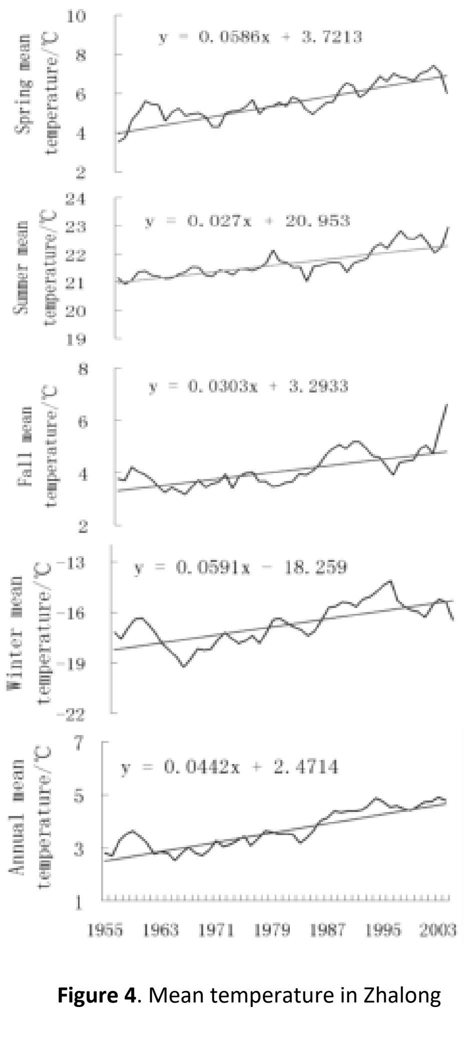


Figure 4. Mean temperature in Zhalong

To annual mean temperature, it was the low temperature period throughout the 1960s and 1970s, in that period, 5 year moving average temperature was negative. Since the middle of 1980s, there was a significant ascend period with fluctuations, it was the highest temperature period in the middle of 1990 s recent 60 years.

The stage changing trend of the Zhalong wetland temperature in spring, fall and winter were in basic agreement on the annual temperature for recent 50 years, it showed that relative cold and warm period appeared in turn, relative cold period was found in the 60 s-80 s metaphase, relative warm period in the 50 s-60 s and the 80 metaphase-the 90 s. In summer, temperature elevated continually without obviously relative cold and warm period.

In Figure 5, the straight line represents the change trend of the annual and seasonal precipitation in Zhalong wetland, the kinked line represents the 5 years moving average of its. Since recent 60 years, the climate tendency rates of annual, spring, summer, fall and winter precipitation in Zhalong wetland were respective -7.3 mm·10a^{-1}, 0.28 mm·10a^{-1}, -2.23 mm·10a^{-1}, -5.10 mm·10a^{-1} and -0.23 mm·10a^{-1}, it showed that annual, summer, fall and winter precipitation have declined, of which, the reduction tendency of fall precipitation is the most obvious from 1955 to 2014.

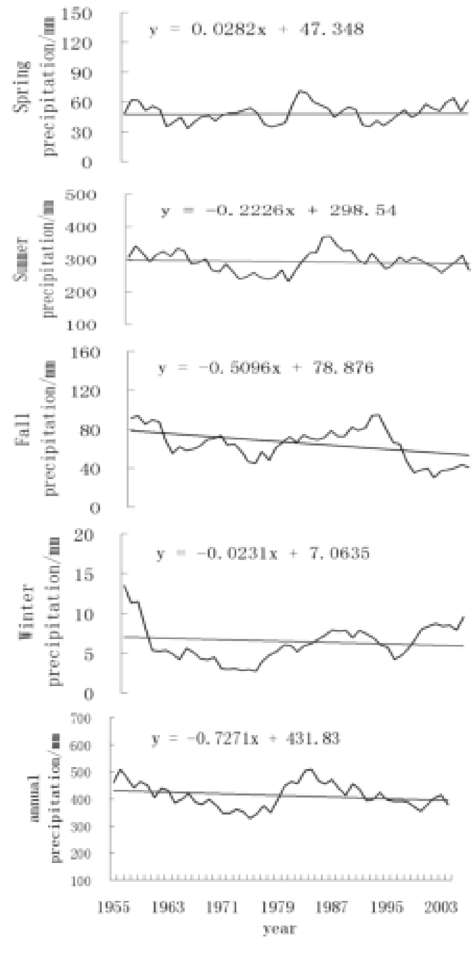


Figure 5. Precipitation in Zhalong

It can be seen from 5 year moving average line that the less precipitation periods were found in 50 s, 60 s and 90 s, the more precipitation period in 80 s, the highest one in 1998. In the Zhalong wetland, the fluctuation range of spring precipitation was narrower, the stage changing trend of summer, fall and winter precipitation with the basic agreement on annual precipitation were greatly decreasing for recent 60 years.

The warm-dry climate trend in Zhalong wetland, to a certain extent, is likely to lead to the contraction of marshland and grassland, the northeast migration of reed swamp, cultivated land and grass land.

4. Conclusions and discussions

The climate in Zhalong became warmer and drier, over the past 60 years, the temperature increased significantly, meanwhile, the precipitation decreased. Human activities including population, construction, water land pollution and production have been threatening the wetland ecosystem. As a result of human activities and climate change, from 1990 to 2014, Zhalong land-use have changed in the way and structure, the cropping area increased, marshland as substrate landscape has been shrunk dramatically, the gravity centers of reed swamp (Sarwar *et al.*, 2019; Soares *et al.*, 2017), cultivated land and grass land migrated to the northeast, landscape variety and landscape evenness index all increased, landscape advantage decreased, Landscape patch shape has be increasingly irregular, Zhalong wetland turned complexed and fragmentation.

Some human activity issues such as population, construction, water land pollution and production have been existed for a long time but not resolved all along, why? That just divulged the disadvantage of the management system. Does ZNR face threats now? I think so. Although we still can see some good phenomena such as the quantity of red-crowned cranes now (400) is a little bit better than that of 1996-ten years ago (346). The total wetland area did not decrease sharply in recent years, but the total amount of avifauna decreased from 100 thousand to less than 10 thousand. The fish has decreased from 46 to 6 or 7, and the fragmentation was believed to be dominant driving force. The water land citing program did have an important role for the Reserve, but it can only keep the red-crowned cranes and other a couple of avifauna being in ZNR. However, considering that the interaction of climate change and human activities could enhance the damage on the wetland, we must do something now to preserve the rare avifauna and also the environment which should be more important for human being.

The interaction of climate change and human activities further promote human and nature damages to the wetland (Henderson- Sellers, 1994). We may not do much to climate change, but we can restrict human activities to reduce the threat of climate warming to the minimum. At present, for sustainable development of Zhalong reserve and in order to preserve the nature of the reserve to maintain the biodiversity, an scientific logical feasible integrated management approach should be adopted, which focus on how to resolve the human activities issues of water land citing, population, construction, pollution and production, meanwhile, deal with well the conflict between the regional economic development and the preserve of wetland (IAMAS, 2005).

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