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Agricultural Development and Implication for Wetlands Sustainability: A Case from Baoqing County, Northeast China

FANG Chong[1, 2], WEN Zhidan[1], LI Lin[1, 3], DU Jia[1], LIU Ge[1], WANG Xiaodi[1, 4], SONG Kaishan[1]

(1. *Northeast Institute of Geography and Agroecology*, *Chinese Academy of Sciences*, *Changchun* 130102, *China*; 2. *University of Chinese Academy of Sciences*, *Beijing* 100049, *China*; 3. *Department of Earth Science*, *Indiana University-Purdue University Indianapolis*, *Indianapolis*, *Indiana* 46202, *USA*; 4. *School of Geography and Tourism*, *Harbin University*, *Harbin* 150086, *China*)

Abstract: Historical thematic maps and remote sensing data were applied to address spatiotemporal dynamics of land use/land cover (LULC) changes and its impact on wetlands sustainability based on eight LULC datasets from 1954 to 2015 in Baoqing County, Northeast China. This study demonstrated that LULC drastically changed in the past six decades due to conversion of wetlands, woodland, and grassland into cropland. The cropland was 578.8 km^2 in 1954, accounting for 5.8% of the area in Baoqing County, and it increased to 54.3% in 2015, which was nearly equivalent to 9.4 times of that in 1954. Cropland increased 4843.6 km^2 from 1954 to 2015 with average increased area of 79.4 km^2/yr. The conversion of wetlands was the main reason for cropland increase (49.7%), and woodland (18%) and grassland (16.3%) conversion were other reasons. Results also revealed that 78% of wetlands were lost during the past six decades, of which 91.2% were converted cropland. Population increasing (population across Baoqing in 2015 was 7.8 times of that in 1949), agricultural technology development was the main reason for cropland increase, institutional and economic policies also played important roles for cropland dynamics, particularly paddy field influenced by market price. Agricultural development has caused severe wetlands degradation both in area and functionality, and still being the major threads for wetlands sustainable development. Several suggestions concerning the future land use policy formulation and wetlands sustainability were proposed. They are adjusting the 'food first' agricultural policy, reinforce management for wetlands nature reserves, creating infrastructure for the rational use of surface and groundwater, harnessing the degraded cultivated land.

Keywords: Baoqing County; cropland; Geographic Information System (GIS); Remote Sensing (RS); wetlands

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1 Introduction

Wetland ecosystems are associated with a diverse and complex array of direct and indirect uses. Direct uses include utilizing of the wetlands for water supply and harvesting of wetlands products such as fish and plant resources, while indirect benefits are derived from environmental functions such as flood retention, coastal protection, groundwater recharge/discharge, and nutrient contamination abatement, depending on the type of wetlands, soil and water characteristics and associated

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Corresponding author: SONG Kaishan. E-mail: songkaishan@iga.ac.cn

biotic influences (Mitsch and Gosselink, 2007; Malekmohammadi and Jahanishakib, 2017; Langan et al., 2018; Sun et al., 2018; Wondie, 2018). Human activities particularly associated with agricultural ones, i.e., cropping and livestock production (Zalidis et al., 1997; Ricaurte et al., 2017) altered the wetlands ecosystem significantly. Land use/land cover (LULC) changes have important consequences for wetlands (Houghton, 1994; Liu et al., 2005), which significantly affect the key aspects of wetlands ecosystem functioning (Jensen et al., 1995; Sala et al., 2000; Ricaurte et al. 2017).

Seidl can play a pivotal role in environmental and ecological changes which in turn contribute to global change (Meyer and Turner II, 1994; Seidl and Moraes, 2000; Pathirana et al., 2014; Kundu et al., 2017). Understanding the causes and consequences of LULC change, and their effects performed on components of functional ecosystems, are the keys for identifying interaction on biological resources and human development (Tolba and El-Kholy, 1992). In fact, our current understanding of the impacts of LULC on managed landscapes is strongly linked to a deep understanding of the socio-economic, biophysical, and proximate forces driving LULC change. The major causes of wetlands loss around the world continue to be conversion to agricultural use, or indirectly degrade due to the change of hydrological regime which is somehow linked to agricultural practices (Mitsch and Gosselink, 2007). However, in many cases, how wetlands have been converted cannot be fully understood due to a lack of socio-economical and biophysical spatial databases (Xie et al., 2005; Gong et al., 2010). Remote Sensing and Geographic Information Systems (GIS) are important tools for evaluating trends in wetlands degradation and their linkages to socio-economic forces (Vitousek et al., 1997; Lambin et al., 2001; Southworth et al., 2004).

The Sanjiang Plain, locating in the Northeast China (Fig. 1), has been undergoing profound changes in LULC. It was used to be the largest concentrated freshwater marshes in China and was still primeval before 1950s. From the late 1950s to the early 1990s, a large number of large farms, distributing all over the plain, were developed concomitant with the losses of wetlands, woodland and grassland. Radical transformation of LULC and agricultural development has undergone due to population increase and increasing demand for food. Now, it is one of the main commodity grain production bases of the nation (Liu and Ma, 2002; Fang et al., 2018; Yan et al., 2018). Due to a large-scale agricultural development, nearly 80% of the wetlands in the Sanjiang Plain have been developed during the past six decades (Liu et al., 2002; Song et al., 2008; Gao et al., 2018; Qu et al., 2018). As a result, wetlands had been degraded dramatically, i.e., shrinkage, fragmentation, or functional deterioration (Guo et al., 2008; Qu et al., 2018). Intensive human activities have led to dramatic change to the ecological environment in the Sanjiang Plain, which were obvious caused by agricultural development since the foundation of China (Song et al., 2008).

Government and environmental experts have been paying more attentions to the planning of the Sanjiang Plain natural resources, especially for cropland planning, as more environmental question arising in recent years (Liu and Ma, 2002). Due to a lack of the necessary spatial and temporal dynamic dataset, few quantitative researches are reported about relatively long time series cropland dynamics in the Sanjiang Plain and its impact on wetlands losses and degradation (Gao et al., 2018). The rate at which wetlands losses on a global scale is only now become clear thanks to the application of new technologies associated with satellite remote sensing (Mitsch and Gosselink, 2007; Orimoloye et al., 2018). However, still many vast areas of wetlands where accurate record is not kept, particularly for the developing countries. Information about wetlands dynamics in the Sanjiang Plain are urgently needed which can facilitate their sustainable development under dramatic influence of human activities.

Baoqing County, which represents the typical landscape in the Sanjiang Plain, Northeast China, is selected for demonstrating the interaction between agricultural development and wetlands sustainability. Being an important commodity grain production county (total grain production was about 1.25×10^6 t/yr (Liu and Ma, 2002)) and experiencing extensive LULC conversion are the second reason for choosing it as a case study. The key objectives of this paper are: 1) to study the spatio-temporal dynamic characteristics of LULC in Baoqing County from 1954 to 2015; 2) to analyze mutual LULC transformation between cropland and wetlands; 3) to explore the driving forces and examine environmental impacts; 4) to propose measures for wetlands sustainable development.

2 Study Area

Baoqing County lies in the central of Sanjiang Plain, Northeast China (Fig. 1), with latitude 45°45′N–46°55′N and longitude 131°12′E–133°30′E, covering a total area of 9983 km^2, which is about 20% of the Sanjiang Plain. Baoqing County comprises 10 towns with a population of 418 536 in 2015, 67.1% of them are engaged in farming practice (Shuangyashan City Bureau of Statistics, 2016), such as cultivating, ditching, fertilizing, and harvesting. The elevation is higher in the southwest and lower in the northeast of the Baoqing County, ranging from 53 m to 682 m (above sea level). This county owns temperate humid and sub-humid continental monsoon climate. The annual average temperature is 3.2℃ with average frost-free period of 130 days per annum. Annual precipitation is 574 mm, up to 80% takes place from May to September (Zhou et al., 2009).

Most of wetlands are situated in the alluvial plain formed by the Naoli River, in addition to a small part of wetlands distribute along streams in the mountainous area. Vegetation in this region belongs to Changbai flora, mainly are meadow and wetlands plants. *Calamogrostis angustifolia* and *Phragmites* (common reed) marsh are the dominating wetlands vegetation widely distributed in Baoqing, *Carex* (sedge), *Typha* (cattail) marsh scattered in some places (Liu, 1995). The major soil types include phaeozem, meadow soil, bog soil and dark brown soil. The landscape in Baoqing County was still pristine before the 1950s; since the end of the 1950s, a great number of farming labors swarmed into this region to develop wetlands, grassland and woodland into cropland. Three national reserves (e.g., Qixinghe, Changlingdao, and Yanwodao Wetland Nature Reserves) and one provincial reserve (Dongsheng Wetland Nature Reserve) are distributed along Naolihe riparian area with relatively pristine habitat to support wetlands flora and fauna in the region (Fig. 1).

3 Materials and Methods

3.1 Images and thematic maps

The LULC datasets, compassing a period of 61 years divided into eight stages (1954, 1976, 1986, 1996, 2000, 2005, 2010, 2015), were used to compare the LULC dynamics in Baoqing County. LULC map for 1954 was derived from topographic maps (1: 50 000) with aided of some aerial photograph and land use thematic maps from three towns (Wanjinshan, Chaoyang and Qingyuan). The LULC maps for other stages were

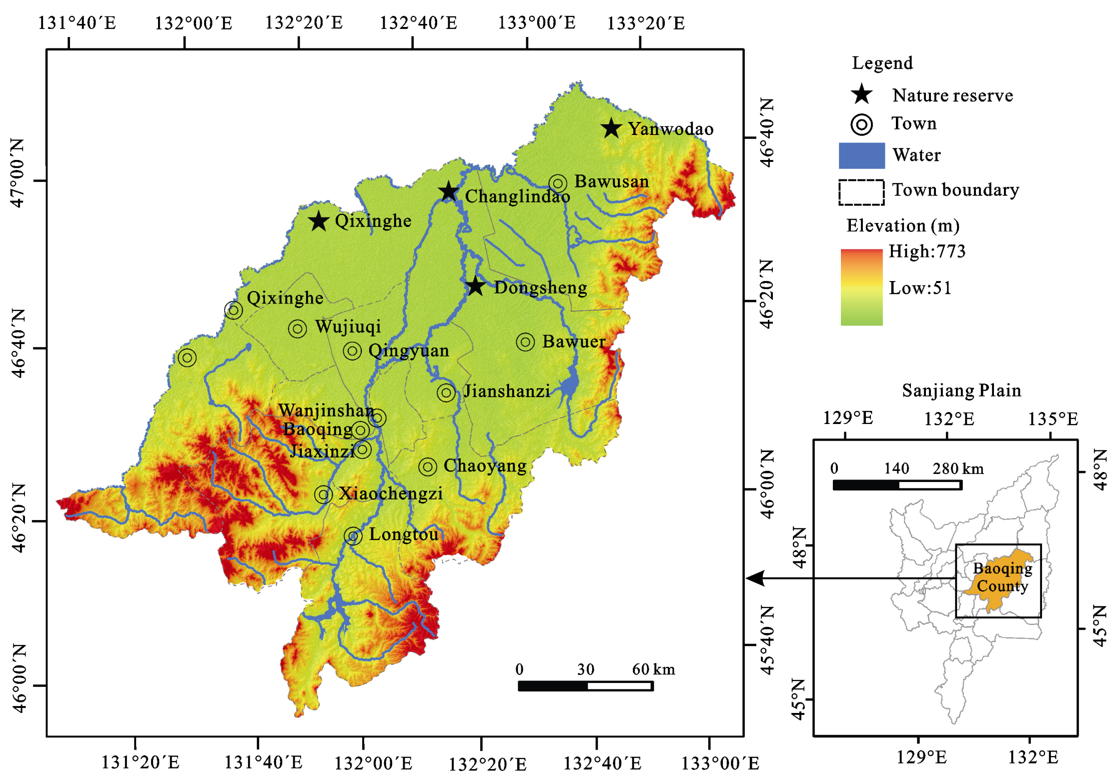

Fig. 1 Geo-location and topography of Baoqing County, Northeast China

derived from Remote Sensing (RS) data (Landsat MSS images data in 1976; Landsat TM (Thematic Mapper) data in 1986, 1996, 2005, 2010, ETM+ (EnhancedThematic Mapper) in 2000 and OLI in 2015) with aid of extensive ground truths. The images meet the following criteria: 1) cloud cover less than 10% over the whole scene; 2) easily identified land use types in the vegetation growth period, from June to late September.

In the ArcGIS 10.3 software package, fishnet modular was used to generate nets of 2-km grid and the Transverse Mercator map frame, and then scanned topographic maps covering Baoqing were registered to this Transverse Mercator projected kilometric net. TM data acquired in 1995 was registered to topographic maps by collecting ground control points from registered topographic maps. Remote Sensing images acquired in 1976, 1986, 2005, 2010 and 2015 were enhanced by using linear contrast stretching and histogram equalization for improving ground control point collection (Liu and Ma, 2002). These were co-registered to the 1995 TM image using ERDAS Imagine 8.4 (ERDAS, Atlanta, GA, USA). The Root Mean Squared Error (RMSE) of the geometric rectification was always less than 1.0 pixel (at 30 m resolution in TM/ETM+/OLI; at 78 m resolution in MSS) for all images.

3.2 Images interpretation

LULC datasets for 1986, 1995 and 2000 were subsets of the corresponding National Land Cover Datasets (NLCD-1986, NLCD-1995 and NLCD-2000), which were developed by scientists from eight institutes of Chinese Academy of Sciences (CAS) through visual interpretation and digitization of TM images on the computer screen (Liu et al., 2002). These subsets were generated by Northeast Institute of Geography and Agroecology (IGA), CAS. NLCD has a classification system of 25 LULC categories at a scale of 1∶100 000, in which cropland includes two subclasses, namely, dry cropland and paddy field.

Supervised or unsupervised classification methodologies have been widely accepted for LULC dataset development (Rao and Pant, 2001; Wang et al., 2006), on-screen digitizing or a combination of auto-classification with manual labeling are still the most accurate procedures for accurate and reliable LULC dataset (Vogelmann et al., 1998; Barson et al., 2000; Büttner et al., 2002). For the dataset consistency, LULC-1976, LULC-2005, LULC-2010 and LULC-2015 were developed with the same procedure followed by NLCD developing protocols (Zhuang et al., 1999; Liu et al., 2005) and same classification system (25 subclasses and 7 major classes). Landsat-MSS/TM color composite (4 = Red (R), 3 = Green (G) and 2 = B (Blue)) in 1976, 2005 and 2010 as well as OLI color composite (5 = R, 4 = G and 3 = B) in 2015 images were interpreted with reference to NLCD-1986 and NLCD-2000 represents the interpreters used ArcGIS 10.3 software to determine and outline the LULC patches on the computer screen based on the object's spectral reflectance, texture, structure and other ancillary information. Additional maps used for helping identification of LULC patches include LULC-1986, LULC-2000, 1∶250 000 vegetation, 1∶50 000 topographic, and 1∶500 000 soil categories maps.

LULC in 1954 was derived from topographic maps (at 1:50 000 scale from State Bureau of Surveying and Mapping of P. R. China, based on aerial photograph and trigonometric field survey during 1950–1953) by digitizing and tracing the LULC boundary on these maps. Considering the accuracy conformity and data comparability, we processed seven-stage datasets with reference to the accuracy of the smallest scale, 1∶100 000, by merging the small polygons with areas less than 0.005 km^2 in datasets from 1954 to 2015. For labeling purpose, all datasets denote as LULC-1954, 1976, 1986, 1995, 2000, 2005, 2010 and 2015 respectively.

3.3 Data accuracy assessment

Part of the NLCD datasets were assessed by field survey (Liu et al., 2005), and assessments of classification accuracy for LULC-2005 were followed with the methods proposed by Liu et al., (2002). Random routes in which accumulated survey length of 448 km were conducted, 332 site-evaluation points were collected with the global positioning system (GPS) along several routes distributed across Baoqing County, 410 photos (some points with two or three photos) were collected (Fig. 2). The longitude and latitude of the cross of each LULC type boundary with the routes were measured. The errors and the routes were registered to the spatial data in 2005, and then transferred to grids with equal size of TM image pixel. By comparing the pixels of the errors with those of the routes, the errors of the classification of the remote sensing images in 2005 were calculated. Because

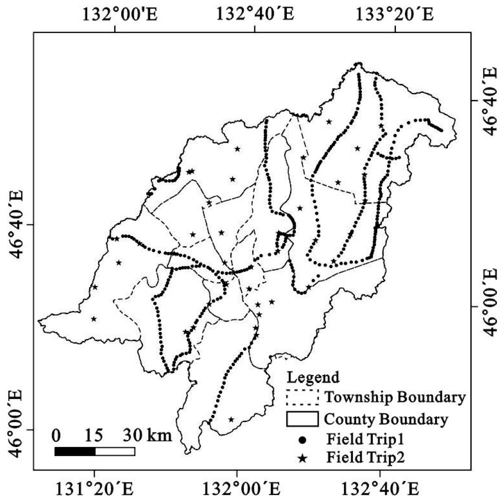

Fig. 2 GPS points collected in field trips for land use/land cover (LULC) validation in Baoqing County, Northeast China

the remote sensing images in 1976 strictly registered with those in 1995 and interpreted referencing to NLCD-1986, the errors of classification in year 1986 could partially represent for those year as well. Vegetation and land use maps concurrent with images in 1976 were collected for LULC-1976 validation.

Our results showed that overall accuracy of the LULC classification for 25 subclasses in 2005 is 93.2%. As for dataset in 1976, for spatial resolution reason, the accuracy is a little bit low, with overall accuracy of 90.7% achieved. Datasets in 1986, 1995 and 2000 were assessed with overall accuracies about 94.0% through field surveys (Liu et al., 2005). LULC dataset in 1954 were mainly assessed by statistical data and land use thematic maps from three towns derived from field surveys. The accuracy for cropland was about 87.0%, and woodland was about 91.0%, grass land and wetlands were 85.0% and 87.0%, built-up and water bodies had the highest accuracy of 94.0% and 98.0%, respectively. The relatively accurate spatial datasets are the fundamental basis for quantitative analysis of LULC dynamics.

3.4 Data analysis methods

LULC change information was acquired by a cross-tabulation detection method using ArcGIS 10.3 software package. A change matrix was produced, and quantitative data of the overall LULC changes, gains and losses in each category can be obtained (Jia et al., 2004). LULC annual change rate (*K*) model was also applied in this study, which can be expressed as:

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

where U_b is area of a specific LULC at the end of study period, and U_a is that at the beginning of the study period, T is the interval of the study period.

To determine socio-economic factors and to develop interventions influencing from cropland development on other LULC dynamics, a series of participatory workshops and interviews were conducted with the local farming residents. Historical information about natural resource and agricultural economy statistic data and policies of the region for the last six decades was obtained to provide an ancillary context for analysis theirs impacts on LULC change in the county (Baoqing County Bureau of Statistics, 1949–2006; Shuangyashan City Bureau of Statistics, 2006–2016).

4 Results

4.1 Land use/land cover (LULC) dynamics

Natural resource management is a complex undertaking, influenced by environmental, economic, social and political factors (Houghton, 1994; Rao and Pant, 2001; De los Santos-Montero and Bravo-Ureta, 2017; McKinley et al., 2017). Analysis of the major LULC change from 1954 to 2015 indicated that LULC underwent significant modifications (Fig. 3 and Table 1) in Baoqing. The most noticeable changes of LULC were the quick areal decline in wetlands, grassland and woodland, concurrent with an obvious increase in cropland during 1954–2015.

Cropland area increased from 5.8% in 1954 to 54.3% in 2015, with annual change rate (*K*) equals to 16.80% during 1954–1975, 6.40% during 1976–1985, 1.10% during 1986–1995, 1.40% during 1996–2000, 0.20% during 2001–2005, 0.60% during 2006–2010 and 0.10% during 2011–2015 (Fig. 4). Wetlands took up 32.80% of Baoqing County, which was about 3276.3 km^2 in 1954, the percentages were reduced to 25.00%, 10.00%, 7.60%, 7.10%, 7.10%, 7.30% and 7.30% in 1976, 1986, 1995, 2000, 2005, 2010 and 2015, respectively, and the total wetlands area was about 725.7 km^2 in 2015. The total wetlands loss area was 2550.6 km^2 with annual wetlands decreased area of 41.8 km^2 during 1954–2015. Correspondingly, the *K* value was –1.30% during whole study period, it varied from –1.10% during 1954–1975 to –6.00% during 1976–1986, –2.70% during 1986–1995,

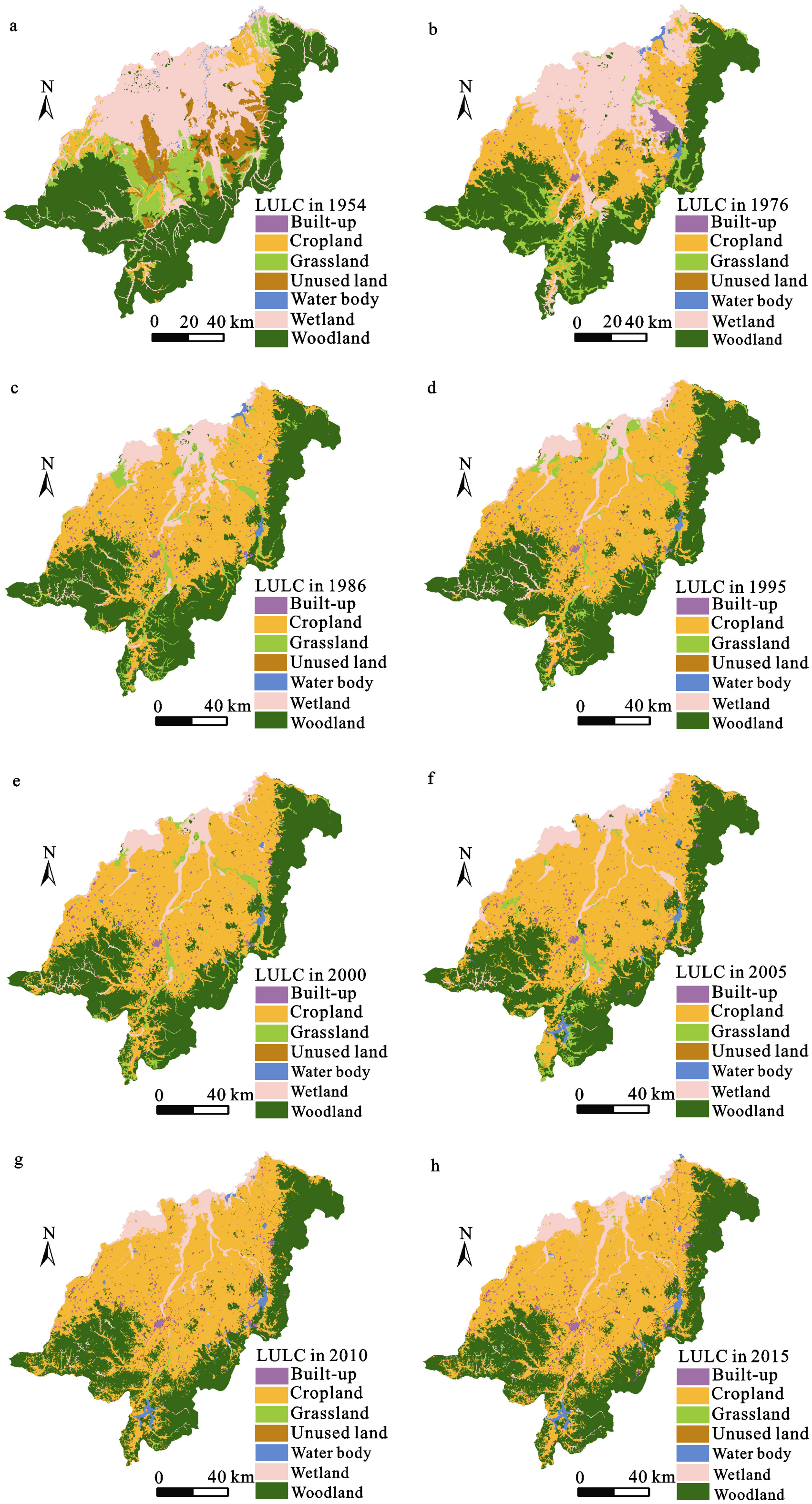

Fig. 3 The land use/land cover (LULC) maps of Baoqing County, Northeast China from 1954 to 2015: a. 1954; b. 1976; c. 1986; d. 1995; e. 2000; f. 2005; g. 2010; h. 2015

Table 1 The land use/land cover (LULC) descriptive statistic information in Baoqing County, Northeast China from 1954 to 2015

Year	Items	Cropland	Woodland	Wetland	Grassland	Water-body	Built-up	Unused land
1954	Area (km^2)	578.8	4178.5	3276.3	999.0	32.2	13.5	904.9
	proportion (%)	5.8	41.9	32.8	10.0	0.3	0.1	9.1
1976	Area (km^2)	2712.2	3861.0	2499.0	675.8	51.4	183.8	0.0
	proportion (%)	27.2	38.7	25.0	6.8	0.5	1.8	0.0
1986	Area (km^2)	4454.9	3799.3	999.6	514.9	57.7	156.1	0.5
	proportion (%)	44.6	38.1	10.0	5.2	0.6	1.6	0.0
1995	Area (km^2)	4876.4	3732.9	753.8	418.3	38.4	162.7	0.6
	proportion (%)	48.9	37.4	7.6	4.2	0.4	1.6	0.0
2000	Area (km^2)	5210.6	3531.0	705.2	335.8	42.9	157.2	0.6
	proportion (%)	52.2	35.4	7.1	3.4	0.4	1.6	0.0
2005	Area (km^2)	5262.7	3456.8	706.5	315.5	83.3	155.2	3.1
	proportion (%)	52.7	34.6	7.1	3.2	0.8	1.6	0.0
2010	Area (km^2)	5407.5	3537.0	726.3	41.7	105.7	164.3	0.3
	proportion (%)	54.2	35.4	7.3	0.4	1.1	1.7	0.0
2015	Area (km^2)	5422.4	3517.1	725.7	17.2	102.7	194.1	3.7
	proportion (%)	54.3	35.2	7.3	0.2	1.0	1.9	0.0

–1.30% during 1996–2000, –0.04% during 1996–2005, 0.60% during 2006–2010 and –0.02% during 2011–2015, respectively. The considerable decrease in wetlands and concomitant increase in cropland resulted from the rapid spread of commercial agricultural product demand and inadequate legal and institutional regulations for wetlands protection.

Similar to wetlands shrinking, woodland areas kept decreasing in the whole study period with K values ranging from –0.40% to –0.10% (Fig. 4). Grassland decreased 981.8 km^2 in the past six decades. The same is for unused land in Baoqing County, its percentage decreased to 0.04% during 1954–2015. Grassland also changed dramatically, 98.3% was lost during 1954–2015. It can be seen from Table 1 that built-up area kept increasing from 13.5 km^2 in 1954 to 194.1 km^2 in 2015, the area in 2015 is about 14 times of that in 1954, which is concomitant with population increase trend in Baoqing County from 1954 to 2015.

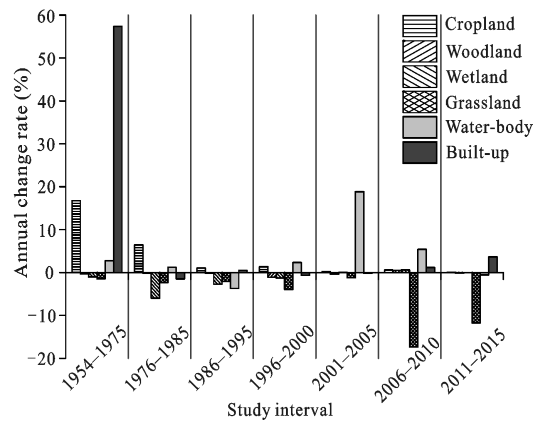

Fig. 4 The land use/land cover (LULC) change rate (K) in 1954–1975, 1976–1985, 1986–1995, 1996–2000, 2001–2005, 2006–2010, 2011–2015 in Baoqing County, Northeast China

4.2 Cropland and wetlands dynamics

The cropland change magnitude, rate and its relation to other LULC types varied during the seven intervals. From 1954 to 1975, cropland increased 2133.5 km^2 (Fig. 5), which was mainly converted from wetlands, grassland and woodland (Table 2). The average annual net increase of cropland was about 96.98 km^2. During 1976–1985, cropland increased 1742.7 km^2 (Fig.5), again it was mainly converted from wetlands, woodland and grassland. The average annual increase of cropland was about 174.3 km^2 indicating that agricultural development activities were more severe in this period. During 1986–1995, the average annual change area of cropland slowed down compared with the former two periods. Wetlands still overtook woodland and grassland for cropland increase. It was obvious that the annual converted area and speed had much slowed. In the next five years (1996–2000), cropland increased about 334.1 km^2 and the average annual change amount to 66.8 km^2 (Fig. 5). Woodland conversion to cropland overtook

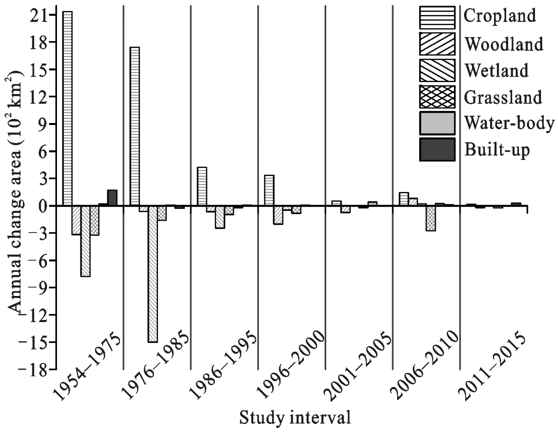

Fig. 5 The annual net change area for various land use/land cover (LULC) types of Baoqing County, Northeast China in 1954–1975, 1976–1985, 1986–1995, 1996–2000, 2001–2005, 2006–2010, 2011–2015

wetlands and grassland. The change during 2001–2005 is extremely similar with the period 1996–2000 (Table 2). Different from previous two periods, the average annual change area of cropland in 2006–2010 showed a small peak, and wetlands contributed most compared with woodland and grassland for cropland increase. In the last study period 2011–2015, the net increased area of cropland was 14.9 km^2, presented a similar trend with previous periods (1996–2000, 2001–2005) by dominant woodland conversion.

During 1954–2015, cropland increased 4946.4 km^2 of which 49.7% was converted from wetlands, and the rest mainly converted from woodland and grassland, indicating that cropland kept on increasing at the cost of wetlands losses and partly from woodland and grassland. Different spatiotemporal characteristics for cropland revealed for various study periods. The wetlands conversion was the major contribution for the increase of cropland during 1954–1995, 2011–2015. It was worth noting that wetland decreased rapidly during the first period due to its ideal potential arable landscape and its convenience for cultivation. The same situation is also applicable to grassland. Agricultural development turned to woodland when arable wetlands and grassland become rare or has been set aside for conservation, and this was the case for cropland development during 1996–2010.

Above analyses revealed that wetlands are mainly converted to croplands for agricultural development in Baoqing County with the rest converted to other LULC types directly or indirectly associated with agricultural development. Table 3 shows the ratio of wetlands converted to other LULC types in Baoqing County. It revealed that 68.3% wetlands converted to cropland, 13.9% to grassland; almost similar amount to woodland and water body during 1954 to 1985, with very small portion turned to residential and unused. Overall, more than 91.2% of lost wetlands turned into cropland in the whole study period, which accounted for 2693.4 km^2.

5 Discussion

5.1 The impact of demographic development on cropland

Both demographic and socio-economic considerations play important roles in the natural resource dynamics (Guyer, 1997; Rao and Pant, 2001; Kim and Lim, 2017; Dumitraşcu et al., 2018), which holds for the natural resource management in Baoqing. The population was 5.38 × 10^4 in 1949 (5.4 person/km^2), and increased to 4.20 × 10^5 in 2015 (Shuangyashan City Bureau of

Table 2 Area (km^2) and proportions (%) of other land use converted to farmland of Baoqing County, Northeast China in different periods

Periods	Woodland		Wetland		Grassland		Water-body		Built-up		Unused land	
	Area	Proportion	Area	Proportion	Area	Proportion	Area	Proportion	Area	Proportion	Area	Proportion
1954–1975	270.7	11.6	896.3	38.4	581.7	24.9	4.0	0.2	7.3	0.3	574.3	24.6
1976–1985	258.5	13.1	1347.6	68.4	253.6	12.9	0.9	0.0	108.9	5.5		
1986–1995	140.4	26.2	282.9	52.8	110.5	20.6	0.3	0.1	1.4	0.3		
1996–2000	196.5	51.6	66.1	17.4	112.5	29.5	0.1	0.0	5.9	1.5		
2001–2005	173.0	47.5	94.8	26.0	79.3	21.8	3.0	0.8	13.9	3.8		
2006–2010	326.3	45.0	138.4	19.1	184.9	25.5	7.8	1.1	66.5	9.2	1.8	0.2
2011–2015	30.9	22.7	93.7	68.8	5.5	4.0	3.1	2.3	3.0	2.2	0.0	0.0
1954–2015	891.4	18.0	2457.6	49.7	805.0	16.3	13.3	0.3	7.6	0.2	771.6	15.6

Table 3 Statistics of wetland converted to other land use/land cover (LULC) types of Baoqing County, Northeast China from 1954 to 2015 (km^2)

Period	Cropland	Woodland	Grassland	Water-body	Built-up	Unused
1954–1975	896.3	142.1	182.6	30.4	61.7	
1976–1985	1347.6	34.0	223.2	6.7	6.8	
1986–1995	282.9	4.9	48.8	0.0	0.9	
1996–2000	66.1	5.1	0.0	4.3		
2001–2005	94.8	19.9	16.0	14.7	0.0	
2006–2010	138.4	20.6	2.2	5.5	1.5	
2011–2015	93.7	0.3	1.3	3.5	0.3	0.3

Statistics, 2016) with an average population density increased to 41.9 person/km^2. LULC change, particularly cropland expansion is a direct or indirect result under the population pressure. The correlation between population and cropland area in Baoqing County was illustrated in Fig. 6a (Baoqing County Bureau of Statistics, 1949–2006; Shuangyashan City Bureau of Statistics, 2006–2016). Population kept increasing from 1949 to 1990 with two bumps, the first one was concurrent with veteran swamped into Baoqing County (Liu and Ma, 2002), and the second was formed by the educated youth home-returning (see section 5.2 for detail) resulting in trough in 1978 (He, 2000). The population slowed down since 1990 as the result of birth control policies adaptation and surplus labors flowing into urban area. The cropland area followed similar trend with three speed-ups which will be explained in section 5.2 for detail.

Cropland area has close association with population with a determination coefficient (R^2) 0.9. An interesting feature can be noted in the Fig. 6b is that cropland increasing speed is not concurrent with population increasing. From 1990, population increased quite limited, while cropland increased with a fast speed due to modern agricultural machineries were adopted in Baoqing County speeding up cropland cultivation. The population and cropland area are highly correlated, but this trend probably does not hold in future due to limited arable land available in addition to land use policies has been changed (Wang et al., 2006).

5.2 The influence of institutional policies on cropland and wetland

LULC in Baoqing was framed by agricultural and economic policies since the foundation of China. It has witnessed four important stages related to the wetlands reclamation (Fig. 7). First, from 1956 to 1960, about 18 500 veterans swarmed into Baoqing to cultivate wetlands, grassland and woodland aiming to get more food fulfilling the national demand during the 'Great Leap Forward' movement. Second, during 1964–1968, more than 26 000 educated youth came to Baoqing for agriculture development in response to the 'Going to the

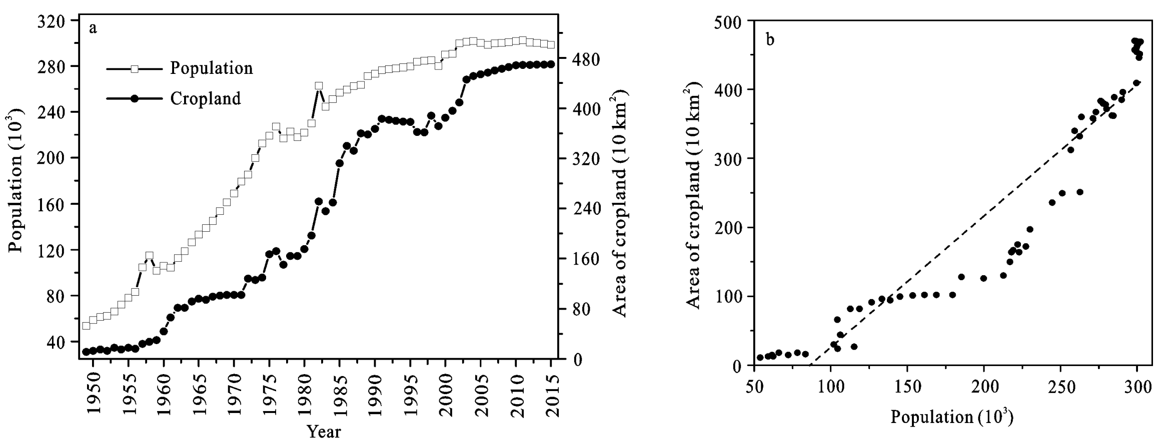

Fig. 6 Dynamics of population and cropland area (a) and the correlation between population and cropland area (b) in Baoqing County, Northeast China

Countryside and Settling in the Communes' movement which was one of the parts to the 'Great Cultural Revolution' (Fig. 6a). The third cultivation peak took place at the initial stage of reform policy adopted, and the last but not the least was due to modern farming machines were introduced and large modernized farms were built in 1980s (Fig. 7).

Since 1992, the market-directed economic system has replaced the former planned economic system. Because rice growing could yield more profit than dry farming, more attentions were paid to the conversion of dry cropland to paddy field. Consequently, the area of reclamation from wetlands decreased notably. Comparing the period 1996–2015 and 1954–1995, the speed of wetlands loss dropped also due to the ecological functions of wetlands were recognized widely and thus national ecological projects such as 'farmland back to wetlands' and 'construction of ecological province for Heilongjiang Province' were adopted and applied. During this period, several national nature reserves were built, including those designated for wetlands of the international importance (Fig. 1). However, the wetlands loss still happened, which decreased the wetlands area and damaged the wetland landscape functionality (Zhang et al., 2010). Therefore, it is necessary to highlight the protection for the wetlands in Baoqing County.

Statistical data of dry cropland and paddy land indicated that paddy field only took up a small portion of cropland before 1979 (Baoqing County Bureau of Statistics, 1949–2006), both dry cropland and paddy field increased at a large scale, particularly paddy field which was mainly converted from dry land (Fig. 8). The paddy field area greatly increased up to 211.6 km^2 in 1995

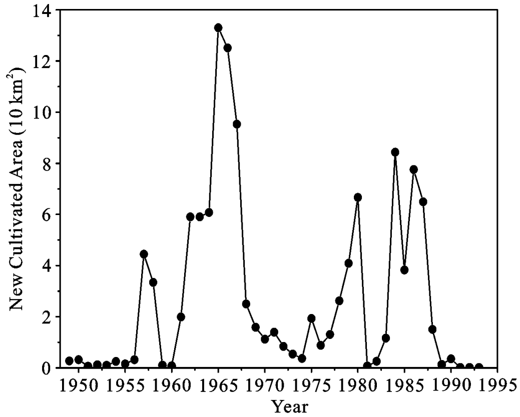

Fig. 7 The dynamics of new cultivated area in Baoqing County, Northeast China

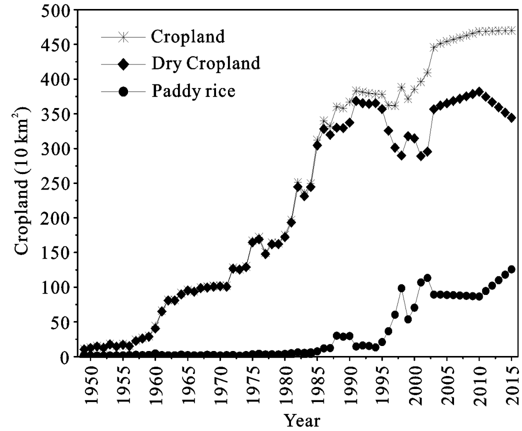

Fig. 8 Dynamics of dry cropland and paddy field in Baoqing County, Northeast China from 1949 to 2015

from 18.8 km^2 in 1979, reaching 704.6 km^2 in 2000, and it rapidly increased in the past fifteen years to 1259 km^2 in 2015. Due to the lower output of the dry farming land, there is a possibility that some farmers would adjust their planting structures from dry cropland to paddy field in the future. The paddy field area in 2015 is almost 10.6 times compared to that in 1986, about 80% of the rice paddy fields irrigated with pumped ground water although Baoqing County is affluent with surface water but no well-established channels to divert surface water for irrigation.

5.3 Major environmental impacts

As reveled by the LULC datasets, over 80% wetlands were converted to cropland or other LULC types. In addition to these losses, many other wetlands have been degraded, although calculating the magnitude of the degradation is difficult. A reduction in the overall area of wetlands can cause a significant decrease in their essential ecological functions (Bedford and Preston, 1988; Klemas, 2001; Chen et al., 2018; Orimoloye et al., 2018). These losses, as well as degradation, have greatly diminished wetlands resources in Baoqing, as a result, the benefits wetlands provided no longer exists or reduces. Recent increases in flood damages, drought damages, soil fertilizing reduction and the declining bird populations are, in part, the result of wetlands degradation and destruction in Baoqing County (Liu and Ma, 1997; Zhang and Song, 2004).

5.3.1 The Impact of wetland converted to cropland on soil physical parameters

Soil organic matter (SOM) has been regarded as one of the most widely recognized indicators of soil quality, which would be depleted through tillage, harvest or increased respiration losses resulted from wetland conversion to cropland (Wallenius et al., 2011; Wang et al., 2012). Meanwhile, reduction on soil organic carbon (SOC) leads to a decline in soil cation exchange capacity and cropland productivity (Houghton et al., 1999). Meadow soil (one of the major soil types), total nitrogen (TN) and total phosphorus (TP) in soil also declined substantially following conversion to agriculture with all soil nutrient levels decreasing most dramatically during the initial 5 years after cultivation. The similar trend follows by available nitrogen, phosphorus and potassium in top soil, but they are much stable in deep soil profile (Shang et al., 2004). Other soil types showed similar trends but to a lesser degree (Song et al., 2004; Zhang et al., 2007).

The conversion of wetlands to cropland results in profound soil water content and temperature alteration (Song et al., 2004). The destruction of soil aggregates exposes SOC to previously inaccessible microbial attack, favoring the SOC decomposing process enhanced through higher land surface temperature (Zhang et al., 2007). Soil physical parameters also change after cultivation and plowing (Gerakis and Kalburtji, 1998). As shown in Table 4, meadow soil structure has changed due to plowing and fertilizing practice for the topsoil (1–16 cm depth). The soil structure of the root zone is destroyed, resulting in the loss of sponge structure. Microbial activities enhance the soil carbon decomposing process to some extent when the anaerobic condition switches to the aerobic condition. As a result, the bulk density and volumic mass increased, whereas soil porosity decreased significantly. Note that bulk density and volumic mass increase for both up- and low-layers with the increase in cultivation years. However, soil porosity generally stabilizes after cultivation of four to five years.

5.3.2 The influence of wetland converted to cropland on groundwater

Groundwater depletion is a key issue associated with groundwater use. More rice growing in Baoqing overused groundwater for ground water pumping rate faster than being recharged. Some wetlands degraded due to the ground water or surface water change since hydrological factors are determinants for wetlands system (Uluocha and Okeke, 2004; Liu et al., 2004). Water-level declines may also affect the wetlands vegetation and animals living habitat. It has been reported wetlands plants in Sanjiang Plain degraded due to water table declined (Zhang et al., 2010), and ultimately affect the habitat for some water fouls (Gerakis and Kalburtji, 1998). Moreover, contaminants introduced through agricultural practice (fertilizer and pesticide) may infiltrate to the ground water and that will take long time to be replaced due to the long retention (Zhu and Yan, 2011; McMurry et al., 2016). Farming people will increase costs for ground water harvesting due to the depth to ground water increased (Liu and Ma, 2002; Wo et al., 2009), also it will ultimately cause land subsidence in the long run (Qi et al., 2009).

6 Conclusions and Suggestions

With the help of GIS, the satellite remote sensing may be one of the most feasible approaches over regularly acquired information for monitoring wetlands dynamics. From 1954 to 2015, wetlands in Baoqing County, Northeast China have significantly reduced due to agricultural development and institutional or economic policies adoption since the foundation of P. R. China. During 1954 to 1995, wetlands were developed intensively, and slowed down during 1996–2015. The results indicated that wetlands losses were mainly converted into cropland (direct degradation), the rest converted to woodland and grassland due to hydrological conditions change under cultivation activities (indirect degradation), which shows that anthropogenic activities are the radical reason of the wetlands losses. In particular, the population pressure was the main factor for wetlands losing in the past decades. A reduction of wetlands caused a significant decrease in their essential ecological functions; consequently, the benefits wetlands provided no longer existed or reduced. Except direct wetlands losses due to drainage and conversion, wetlands also have been degraded in ways that are not as obvious as direct physical destruction or alteration. Efforts and policies still need to be strictly reinforced for wetlands conservation. However, there still several issues should be concerned for wetlands sustainability in the county for they need long term to recover once being damaged or degraded.

Great importance has been recognized to wetlands protection in Baoqing County (4 nature reserves established), while how to manage these nature reserves turns to be a challenge for the wetlands sustainability. Rigorous environmental impacts have to be analysed when towns and infrastructure are constructed around wetlands concentrated area. Furthermore, measures should be taken for the ecological migration (local residents move out from reserves to restore the wetlands ecosystem and protect the environment) to these live in the wetlands nature reserve restriction regions, subsidence or compensation should be made for these ecological migrants, employment training and job opportunities also should be offered. Irrigation infrastructures for surface water diversion should be established as soon as possible for the increased rice growing to avoid overusing ground water.

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