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Quantitative Assessment of Impacts of Regional Climate and Human Activities on Saline-alkali Land Changes: A Case Study of Qian′an County, Jilin Province

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Abstract: Interdecadal and interannual variations of saline-alkali land area in Qian′an County, Jilin Province, China were comprehensively analyzed in this paper by means of satellite remote sensing interpretation, field flux observations and regional climate diagnosis. The results show that on the interannual scale, the impact of climate factors accounts for 71.6% of the total variation of the saline-alkali land area, and that of human activities accounts for 28.4%. Therefore the impact of climate factors is obviously greater than that of human activities. On the interdecadal scale, the impact of climate factors on the increase of the saline-alkali land area accounts for 43.2%, and that of human activities accounts for 56.8%. The impact of human activities on the variation of saline-alkali land area is very clear on the interdecadal scale, and the negative impact of human activities on the environment should not be negligible. Besides, changes in the area of heavy saline-alkali land have some indication for development of saline-alkali land in Qian′an County.

Keywords: saline-alkali land; regional climate change; human activities

1 Introduction

Along with the global change, global warming and the development of social economy, regional climate changes and human activities have greatly altered the natural environment, and correspondingly, land use and land cover have also changed. Webb (1931) considered that the land use was determined by local drought degree; afterwards, Kraenzel (1955) investigated the forest areas and agricultural areas in the South America , the Southeast Asia and Afica, and held that the land use was jointly affected by climatic, economic and social factors.

In the 1970s, the study on the global changes had become one of hot issues in the academic field, and as one of basic anthropogenic factors affecting the global changes, the land use/cover change (LUCC) was very actively studied. In 1995, the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme (HDP) on Global Environmental Change jointly presented the Land Use/Cover Change Programme, and the study on LUCC became a frontier and hot topic of global change research (Committee on Global Change, 1990; Turner, 1990; Meyer and Turner, 1994; Chen and Yang, 2001; Shi *et al*., 2002; Chen *et al*., 2003). In recent years, researchers in North America turned to grid cell automatic recognition models instead of concept models (Turner, 1997), Japanese researchers quantitatively investigated the regional LUCC using quantitative and economic models (Otsubo, 1999; Wu *et al*., 2007), and European researchers simulated the past and current LUCCs to reveal the social and economic driving force of the LUCC.

Studies on LUCC in China advanced rapidly, and some progresses have been achieved in the correlation among climate change, human activity and LUCC (Zhuang and Liu, 1997; Sun *et al*., 1998; Yu and Yang,

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2002; Zheng *et al*., 2003). In the 1990s, the development of land desertification in the west of Northeast China drew much attention (Qiu, 1992; Huang and Meng, 1996; Lian *et al*., 1999; 2001; Lin *et al*., 1999; Sun and Liu, 2001; Ren *et al*., 2002), and some studies qualitatively analyzed the driving forces of the LUCC (Huang *et al*., 2003; Liu *et al*., 2005; Liu *et al*., 2006; Zhang *et al*., 2006; Li and Liu, 2007). In recent years, assessments on the status of land desertification are very active due to the application of the remote sensing, geographic information system and global positioning system (3S) techniques, and the comprehensive assessment method has become the development direction of land desertification assessment, however, there are still some biases and unsolved scientific problems (Li and Zhou, 2002; Yang *et al*., 2004; Chen *et al*., 2005). For instance, there are some difficulties in selecting satellite data. Most existing studies only selected two phase data in different years to reveal the development trend of land desertification, thus the impact of climate anomaly in the current years on the land desertification was often neglected. The randomness problem in selecting remote sensing data arose (Lian and Wang, 2007; Lian *et al*., 2007; Sun and An, 2001). How to separate and quantify the impacts of climate change and human activity on land desertification is a hot spot in the research community (Wang, 2003). Recently, Gao and Liu (2006) hold that in the last 20 years, the dual impacts by climate changes and economic development had led to a shift of Land Use Degree Weight Centre of China northeastward by 5 km; and with regard to Land Use Degree Excursion Intensity, in the east-west direction, 81% is caused by climatic changes and 19% by anthropogenic activities.

Qian′an County in Jilin Province, which is located in the front edge of the soda saline-alkali land (SAL) in the west of Northeast China (Ren *et al*., 2002), was chosen as the study area in this paper. Using four phases data of Landsat TM, and adopting the "3S" System of Jilin Province Landsat Remote Sensing Information Processing and Application, the paper revealed the variation rates of SAL on the interdecadal and interannual scales in Qian′an and the conversion of major land cover types, and attempted to quantitatively assess the impacts of regional climate change and human excessive reclamation and overgrazing on SAL area variation by means of regional climate diagnosis, field flux observation and satellite remote sensing monitoring.

2 Study Area and Methodology

2.1 Study area

Qian′an County (44°38′–45°19′N and 123°25′–124°23′E) lies in a blind drainage area between the Songhua River and the Nenjiang River in the west of Jilin Province, Northeast China, with an area of about 3 616.48 km^2, and is in semiarid-semihumid continental monsoon climate region. The county, with less amount of seasonal surface runoff, is an unique county without rivers in Northeast China, and its waters consist of 74 saline-alkali ponds, wherein water is importable and also unsuitable for irrigation. Therefore, the variation of the water area is only related to the climatic factors, such as precipitation, temperature and evapotranspiration, which greatly simplifies the water budget estimation of Qian′an, as well as the quantitative assessment of impacts of regional climate changes and human activities on the changes of SAL area.

2.2 Data and method

The main data analyzed in this study were the Landsat TM data of the four phases on 2nd October 1988, 22nd September 1996, 25th September 2000, and 12th September 2001. And the monthly precipitation and average monthly temperature from January to December over Qian′an in 1961–2001 were also used in this paper, which were provided by Jinlin Meteorological Bureau, China Meteorological Administration.

The selection of Landsat TM channels, the enhancement processing and the supervised classification of remote sensing images, the information extraction of SAL and other land types referred to Lian *et al*. (1999); the computation of annual and seasonal relative change rates of precipitation referred to Lian *et al*. (2001); and the time series of monthly precipitation and temperature from May to September were also standardized.

Evapotranspiration was estimated using the energy balance equation (Bowen, 1926; Tu *et al*., 2003):

$$R_n = H+LE+G+C \quad (1)$$

where R_n is the net radiation; H is the sensible heat flux; LE is the latent heat flux, L is the latent heat of vaporization of water (about 585 cal/g), E is the evapotranspiration; G is the ground heat flux; and C is the outward advection loss. Variations of G and C over a long period, even several days or one day, can be neglected in comparison with the other terms. In such a case, Equation (1) can be reduced to

$$R_n = H+LE \quad (2)$$

R_n was measured by the TBB-1 net radiometer authenticated by China Meteorological Administration, and H was observed by a Large Aperture Scintillometer (LAS) of the Wageningen University. On the aspect of acquiring the large scale surface water and heat fluxes over the nonhomogeneous underlying surface, the LAS is to some extent able to solve the problem of the limited spatial representativeness of the Bowen ratio method and the eddy covariance measurement method (Hu *et al*., 2003; Lu *et al*., 2005). Details of Qian′an LAS observation refer to Zhi *et al*. (2002).

The regional water budget was estimated by using the soil moisture budget (Huang, 1963), which contains 13 parameters, such as precipitation, slope runoff, etc., some of them are difficult to be obtained. In the arid-semiarid area, some minor factors can be neglected, and furthermore, the runoff can also be neglected because Qian′an has no rivers, except some inner lakes, therefore, the soil moisture budget equation is reduced to the following form (Zhi *et al*., 2003):

$$W_2–W_1 = R–E \quad (3)$$

where W_2 and W_1 are the total amounts of water at the end and beginning of a period, respectively; and R is the precipitation in the period. That is to say, if precipitation is greater than evapotranspiration in a certain period, the water amount is surplus, otherwise it is deficit.

3 Results and Analyses

3.1 Variation in saline-alkali land area on interannual and interdecadal scales

Table 1 gives the variation in saline-alkali land (SAL) area in Qian′an from 2000 to 2001 and its causes. The SAL area in 2001 increased by 65.83 km^2 (8.5%) compaared with that in 2000, in which 71.6% came from the drying of saline-alkali waters and wetlands, and 28.4% from the degradation of grasslands. The interannual variation of farmlands was ignored, because it was very small.

Table 1 Variations of SAL area in 2000–2001 and its causes in Qian′an

SAL	Area in 2000 (km^2)	Area in 2001 (km^2)	Variation in 2000–2001 (km^2)	(%)	Cause for area variation
Heavy	696.11	712.84	+16.73	+2.4	
Medium	76.54	125.65	+49.10	+64.1	
Total area	772.65	838.49	+65.83	+8.5	40.8% from reduction in saline-alkali waters 30.8% from reduction in wetland 28.4% from degradation of grassland

It can be seen from the comparison between the interpretation results of 1988 and 1996 (Lian *et al*., 1999; Ren *et al*., 2002) that during the eight years (the period more than eight years generally represents the interdecadal scale), land cover types with a larger area variation are orderly grassland (–63.1%), farmland (+26.2%), SAL (+51.5%), and saline-alkali waters (–44.5%). Table 2 shows the variation in SAL area in Qian′an from 1988 to 1996 and its causes. The reduction in waters and wetland contributed 43.2% to the total increment of SAL area, while the degradation of farmland and grassland accounted for the rest 56.8%.

It can be found from the comparison of the variations between medium SAL and heavy SAL in Table 1 and Table 2 that the interannual variation of medium SAL area (64.1%) was much more distinctive than that of heavy SAL area (2.4%); while on the interdecadal scale the relative variation in heavy SAL area reached 59.1%, far greater than that (19.2%) in medium SAL area. Apparently, whether on the interannual scale or the interdecadal scale, the variation rates of the heavy SAL area were about the same order of magnitude as that of the total SAL area. Therefore, monitoring variation of heavy SAL area has indication for the development of land salinization in Qian′an.

3.2 Estimation of water budget in growing season

Winter precipitation in Qian′an is about 50 mm, accounting for about 10% of the annual precipitation, therefore the water budget only in the growing season (May–September) was considered. The water budget in 2000–2001 was estimated using the field observation data (net radiation, sensible heat flux, *etc*.) and Equations (1)–(3) (Table 3). The water budget in 1988–1996 was not estimated because Qian′an Large Aperture Scintillometer (LAS) station was established in 1999.

Table 2 Variations of SAL area in 1988–1996 and its causes in Qian′an

SAL	Area in 1988 (km^2)	Area in 1996 (km^2)	Area variation in 1988–1996 (km^2)	(%)	Cause for area variation
Heavy	423.76	674.28	+250.52	+59.1	
Medium	100.22	119.47	+19.25	+19.2	
Total area	523.98	793.75	+269.77	+51.5	37.4% from reduction in saline-alkali waters 5.8% from reduction in wetland 56.8% from degradation of grassland and expansion of farmland

Table 3 Water budget in growing season in 2000–2001

	2000 (mm)	2001 (mm)	Variation in 2000–2001 (mm)	(%)
Precipitation	434.7	209.2	–225.5	–51.9
Evapotranspiration	411.3	373.4	–37.9	–9.2
Water budget	+23.4	–164.2		

It can be seen from Table 3 that on the one hand, the interannual variation in evapotranspiration was smaller than that in precipitation, the difference of precipitation between 2000 and 2001 was 225.5 mm, while that of evapotranspiration was only 37.9 mm; and on the other hand, the difference in the water budget between the two years was large, the budget in 2000 was +23.4 mm, while the budget in 2001 was –164.2 mm. Therefore, even if the precipitation in growing season decreased, the total evapotranspiration did not declined in proportion, so the water deficit could happen and the environment drought might be increasing. This is consistent with the 8.5% increment of the SAL area in 2001 (Table 1). Therefore, as far as interannual variation of SAL area is concerned, the increase/decrease in precipitation, as well as the surface evapotranspiration are both very important.

3.3 Impacts of regional climate and human activity on land salinization

The precipitation in growing season, SAL and waters areas in Qian′an in 1988, 1996, 2000 and 2001 were compared successively (Table 4). For the purpose of comparison convenience, the standardized time series of the total precipitation and average temperature in growing season from 1961 to 2002, and variations of the saline-alkali waters and SAL areas during the periods of 1988–1996, 1996–2000, and 2000–2001 were showed in Fig. 1 and Fig. 2 respectively.

It can be seen from Fig. 1 and Fig. 2 that the climate in Qian'an has become warm/dry since the mid-1990s, which accords with the expansion of SAL area. Variations in the saline-alkali waters area and the precipitation in growing season were in phase, but variations in SAL area and the average temperature in growing season were out of phase. The mean temperature in growing season had some impact on variations in saline-alkali waters area and SAL area, but its impact was much less than that of the precipitation in growing season.

The time series of precipitation in growing season in Fig. 1 also shows a typical wavy pattern. The years when the anomaly of the precipitation exceeded ±1.2σ were defined as a positive/negative anomalous years respectively. There were nine anomalous years in total, accounting for 21.4% of the 42 years (1961–2002), therefore, the positive and negative anomalous years of the precipitation were basically within 10% respectively. Therefore, the driving forces of extreme precipitation events for saline-alkali waters and SAL area variations were very robust.

Table 4 shows that the interdecadal and interannual variations of the saline-alkali waters area and total precipitation in growing season in Qian'an are both larger, but their trends are in a similar phase (Fig. 1). The area of saline-alkali waters decreased 44.5% from 1988 to 1996, but the SAL area increased 51.5%, which was consistent with the warm/dry climate trend of the west of Northeast China in the mid-1990s (Lian *et al.*, 2001; 2005; An *et al.*, 2002; Liu *et al.*, 2003; Lian and Wang, 2007). In 1998, an exceptionally serious flood happened in the Songnen Plain, directly resulting in the increase of 84.72 km^2 (+65.2%) in saline-alkali waters area in 2000 compared to that in 1996, and the waters area basically returned to that of 1988. However, due to the exceptional severe drought, the standardized growing season precipitation decreased 3.0σ (Fig. 2) (Table 3), and the deficit of water budget reached 164.2 mm (+44%), resulting in the reduction of 29.8% in waters area and the increase of 8.5% in SAL area in 2001 in comparison with those in 2000 (Table 4).

Table 4 Variations in precipitation, saline-alkali waters and saline-alkali land area in Qian'an

	Precipitation in growing season		Saline-alkali waters area		Total SAL area	
	(mm)	(%)	(km^2)	(%)	(km^2)	(%)
1988	466.70		226.92		523.98	
1996	242.70		125.95		793.75	
2000	434.70		210.67		772.65	
2001	209.20		147.87		838.49	
1988–1996	–224.00	–48.0	–100.97	–44.5	–	+51.5
1996–2000	+192.00	+79.1	+84.72	+65.2	–21.10	–2.7
2000–2001	–225.50	–51.9	–62.80	–29.8	+65.84	+8.5

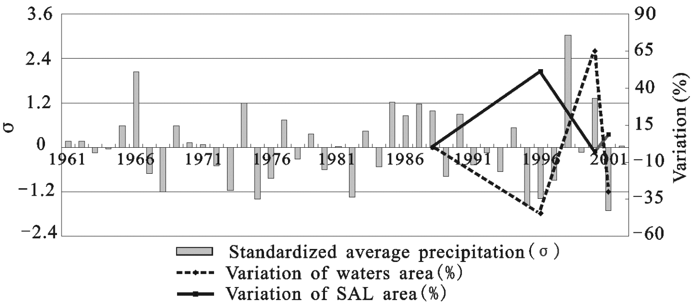

Fig. 1 Total precipitation in growing season and variations of waters and SAL areas after 1988 in Qian′an

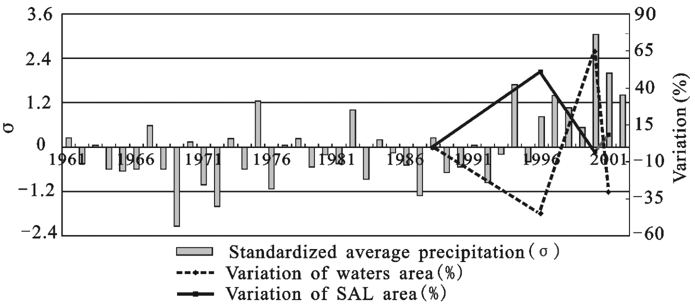

Fig. 2 Average temperature in growing season and variations of waters and SAL areas after 1988 in Qian′an

It can be held that the interdecadal and interannual variations of waters (saline-alkali waters) and wetland, major types of land cover in Qian′an, are mainly affected by climate. So the change in SAL area associated with the changes of saline-alkali waters and wetland should be attributed to climatic factors. The increase of 43.2% in the SAL area of Qian′an from 1988 to 1996 was transformed from waters and wetland (Table 2), and the increase of 71.6% in SAL area from 2000 to 2001 came from the reduction of waters and wetland (Table 1), indicating that the impact of the climatic factors on the interdecadal scale accounted for 43.2% of variation in SAL area, while the impact on the interannual scale accounted for 71.6%. Variations in farmland and grassland areas were mainly affected by human activities, and the related variation in SAL area was mainly caused by excessive reclamation and overgrazing. Indeed, the impact of the warm/dry trend of climate also accounted for the variation to some extent. It can be found from Table 1 and Table 2 that human activities accounted for 56.8% of the interdecadal variation, and 28.4% of the interannual variation in SAL area, respectively.

Therefore, for the variation in SAL area on the interdecadal scale, the effect of farmland expansion and grassland reduction was approximately equivalent to that of the reduction of waters and wetland due to the warm/dry trend of climate, while, on the interannual scale, the impact of the warm/dry trend of climate was obviously greater than that of human activities.

4 Conclusions

The specific geologic and geographic environment of Qian′an County, Jilin Province, provides the simplified condition for understanding the mechanism of land salinization. The interdecadal and interannual variations in SAL area have been analyzed comprehensively by the way of satellite remote sensing interpretation, field flux observation, and regional climate diagnosis. It can be concluded that for the interannual variation of land salinization, the impact of climate was the main factor (71.6%), and that of human activities was the second (28.4%), while for the interdecadal variation, the impact of human activities (56.8%) was greater than that of climate (43.2%). The negative impact of human activities on the environment is not negligible. Qian′an is one of areas where land salinization distinctively developed due to excessive reclamation and overgrazing in Jilin Province, and lies in the west of the Songliao Plain, a national main grain production region. Therefore, the comprehensive management and protection of ecological environment in Qian′an is important for national grain safety.

The relative variation of heavy SAL area on interannual and interdecadal scales were more close to the relative variation of total SAL area, therefore, the variation of the heavy SAL area has some indication for the development of land salinization in Qian′an.

This paper is only a preliminarily attempt to quantitatively assess the effect of regional climate and human activities on SAL area variation. The impact of climate is only partly separated from that of human activities, meanwhile the impact of excessive reclamation and overgrazing on SAL area variation still contains the effect of the warm/dry trend of climate. To solve this problem, numerical simulation should be adopted in future research work.

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