

Accuracy assessment of approaches to spatially explicit reconstruction of historical cropland in Songnen Plain, Northeast China

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Abstract: To understand historical human-induced land use/cover change (LUCC) and its climatic effects, it is essential to reconstruct historical land use/cover changes with explicit spatial information. In this study, based on the historically documented cropland area at county level, we reconstructed the spatially explicit cropland distribution at a cell size of 1 km × 1 km for the Songnen Plain in the late Qing Dynasty (1908 AD). The reconstructions were carried out using two methods. One method (hereafter, referred to as method I) allocated the cropland to cells ordered from a high agricultural suitability index (ASI) to a low ASI, but they were all within the domain of potential cropland area. The potential cropland area was created by excluding natural woodland, swamp, water bodies, and mountains from the study area. The other method (hereafter, method II) allocated the cropland to cells in the order from high ASI to low ASI within the domain of cropland area in 1959. This method was based on the hypothesis that the cropland area domain in 1959 resulted from enlargement of the cropland area domain in 1908. We then compared these two reconstructions. We found that the cropland distributions reconstructed by the two methods exhibit a similar spatial distribution pattern. Both reconstructions show that the cropland was mostly found in the southern and eastern parts of the Songnen Plain. The two reconstructions matched each other for about 68% of the total cropland area. By spatially comparing the unmatched cropland cells of the two reconstructions with the settlements for each county, we found that unmatched cropland cells from method I are closer to settlements than those from method II. This finding suggests that reconstruction using method I may have less bias than reconstruction with method II.

Keywords: comparison of methods; cropland cover; late Qing Dynasty; Songnen Plain, Northeast China

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1 Introduction

In recent times, nearly 40% of the Earth's land (excluding ice shell) cover has been substantially modified by human activities, primarily by the expansion of agriculture (Ramankutty *et al.*, 2008; Ellis *et al.*, 2010; Ye *et al.*, 2009). Agricultural developments modify the physical properties of the Earth's surface (e.g. surface albedo, roughness, transpiration, carbon fixation), thereby affecting regional and global climates (Bonan, 2008; Pielke *et al.*, 2002; Brovkin *et al.*, 2006; Pitman *et al.*, 2011; Houghton *et al.*, 2012). The global climate implications of changes in land cover are controversial; however, it is generally accepted that changes in land cover may regulate the climate at the local or regional levels as important as CO₂ emissions from burning fossil fuels (Forster *et al.*, 2007; Findell *et al.*, 2009). It is therefore necessary to reconstruct historical land cover datasets to improve our understanding of climatic effects. Furthermore, studying the regional climatic effects of changes in land cover can contribute to understanding the dynamics of climate change.

Many historical land cover datasets have been established on global and regional scales. Among them, two representative global land use datasets have been produced by the Center for Sustainability and the Global Environment (SAGE 2010), University of Wisconsin (Ramankutty *et al.*, 2010) and the History Database of the Global Environment (HYDE 3.1), Netherlands Environmental Assessment Agency (Goldewijk *et al.*, 2011). The spatial resolution of SAGE is 0.5° latitude by longitude grid cells, and the time resolution is 10 years from 1700 to 1992. HYDE has a higher spatial resolution of 5 minute grid cells, and the time resolution is 10 years from 1700 to 2005. However, both the SAGE and the HYDE datasets were only applied to research on a global, rather than a regional, scale (Li *et al.*, 2011). Li *et al.* (2010) pointed out that both SAGE and HYDE had obvious errors in the historical reconstruction of cropland area and spatial distribution in Northeast China. In China, there are also numerous published reconstructions, such as those of Lin *et al.* (2008), He *et al.* (2011), Li *et al.* (2012) and Ye *et al.* (2009). Lin *et al.* (2008) selected slope, altitude and population density as the main factors determining land-use suitability. These factors were used to design an empirical model for allocating the historical cropland inventory data spatially to grid cells in each political unit (at 60 km × 60 km resolution). The study then reconstructed the gridding spatial distribution pattern of cropland in the traditional cultivated region in China in 1820. He *et al.* (2011) reconstructed the gridding spatial distribution pattern of cropland in the Northern Song Dynasty (at 60 km × 60 km resolution), and the approach was also used in Lin *et al.* (2008). Li *et al.* (2012) designed a method to quantify the relationship between topography, production potential of climate, population density and cropland spatial pattern. The method was used to reconstruct cropland spatial patterns with a resolution of 10 km × 10 km in Southwest China for six periods between 1661 and 1784 in the Qing Dynasty. Ye *et al.* (2009) reconstructed historical cropland cover change in Northeast China over the last 300 years (hereafter, CNEC) through unification processes including documentary data calibration and a multi-sourced data conversion model.

The above studies are characterized by imprecise results that croplands occupy a certain fraction of each grid cell rather than there being accurate spatial location information about cropland. Furthermore, several previous studies have attempted to reconstruct spatially explicit cropland through infrared remote sensing images. Bai *et al.* (2007) developed a digital

rebuilding of the LUCC spatial-temporal distribution model, wherein several land use rules are used, along with several remote sensing images, to estimate the spatial distribution of land cover in Dorbet Mongolian Autonomous County in Daqing city in the 1930s and 1950s. Li *et al.* (2011) proposed the hypothesis that historical cropland was located in the domain of the present cropland area. They took account of the limiting factors (slope and elevation), then reconstructed the spatial distribution of cropland (at $90\text{ m} \times 90\text{ m}$ resolution) in Yunnan province in 1671 and 1827, within the cropland domain determined by the MODIS land cover product. These studies are based on current land use/cover information abstracted from remote sensing images, and have high-resolution spatial location information. However, these studies failed to deal adequately with developments and changes in LUCC in each period of history, and have various limitations.

All the aforementioned studies on the reconstruction of historical cropland spatial patterns can be summarized as two methods. One method (method I) was based on historical data (e.g. official data, documentary records, survey data), then combined with an empirical model for allocating the historical cropland inventory data to reconstruct cropland distribution. The other method (method II) was based on modern remote sensing data, and the hypothesis that the historical cropland area is all included in the modern area. This was then used to reconstruct the cropland spatial pattern with models. In this study, we selected Songnen Plain in Northeast China as a case study area to reconstruct the spatially explicit cropland distribution in the late Qing Dynasty (1908 AD) at a pixel size of 1 km in two ways. Then, we compared the results with the method of average coordinates of settlements, and set out to assess the validity of applying the spatially explicit reconstruction of cropland.

2 Study area

The study area was located in the Songnen Plain between $42^{\circ}30' - 51^{\circ}20' \text{N}$ and $121^{\circ}40' - 128^{\circ}30' \text{E}$ in Northeast China, covering an area of about $23.75 \times 10^4 \text{ km}^2$ (approximately 2.47% of China's total: Figure 1). This study area has a temperate continental monsoon climate, characterized by significant winds, four seasons, and a hot and rainy summer and a cold and dry winter. The Songnen Plain is mostly flat with few hills, and is an average of 202 m above sea level. The soil is fertile in the Songnen Plain, and black soil, meadow soil and chernozem are widely distributed in this region.

3 Methods

3.1 Estimation of cropland area in the late Qing Dynasty

The work reported here aimed to compare the accuracy of reconstruction by two ways. Both method I and method II are based on historical cropland area, and the late Qing Dynasty cropland area data are used as an initial condition for spatially identifying historical croplands in the past for each political unit. We retried the cropland area in 1908 through documentary data calibration and a multi-sourced data conversion model. In 1908, the cropland area data were compiled from the *Survey Report of Manchurian Railway* (LPA, 2008) and the *Local Gazette of Manchu-Mongolia* (CSMR, 1923). The two sources partly overlapped with each other and could therefore be compared.

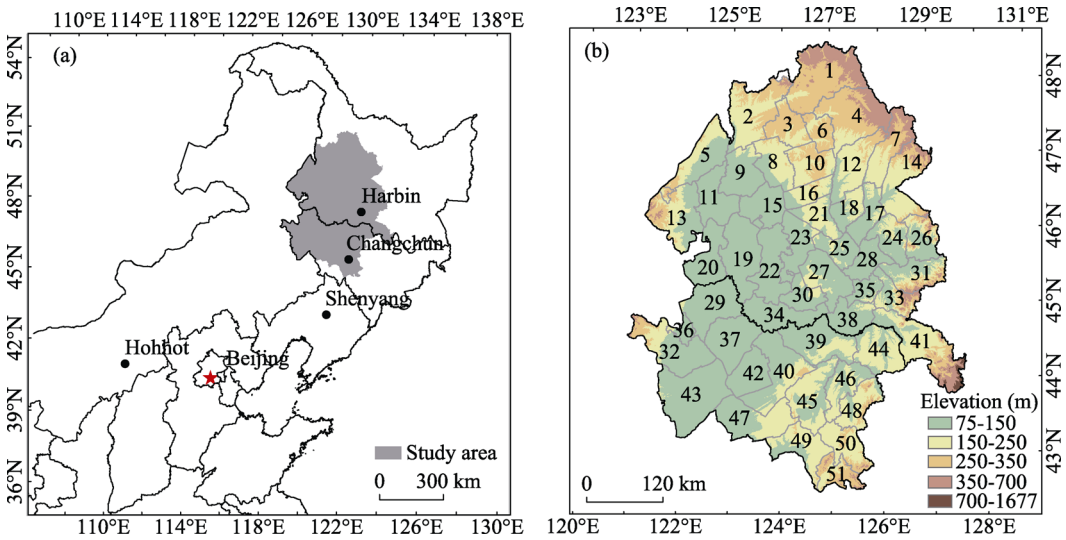


Figure 1 Location of the Songnen Plain (a) and the distribution of counties (b)
Counties: 1. Wudalianchi, 2. Nehe, 3. Keshan, 4. Beian, 5. Gannan, 6. Kedong, 7. Suiling, 8. Yan, 9. Fuyu, 10. Baiquan, 11. Qiqihar, 12. Hailun, 13. Longjiang, 14. Qing'an, 15. Lindian, 16. Mingshui, 17. Suihua, 18. Wangkui, 19. Dorbot, 20. Tailai, 21. Qinggang, 22. Daqing, 23. Anda, 24. Bayan, 25. Lanxi, 26. Mulan, 27. Zhaodong, 28. Hulan, 29. Zhenlai, 30. Zhaozhou, 31. Binxian, 32. Taonan, 33. Acheng, 34. Zhaoyuan, 35. Harbin, 36. Baicheng, 37. Da'an, 38. Shuangcheng, 39. Fuyu, 40. Guoqianqi, 41. Wuchang, 42. Qian'an, 43. Tongyu, 44. Yushu, 45. Nongan, 46. Dehui, 47. Changling, 48. Jiutai, 49. Gongzhuling, 50. Changchun, 51. Yitong

We first converted the traditional units of historical cropland area into square kilometers (km^2). Then, we estimated the area of cropland, based on the population by regression, the area of cropland at county level against population, and on the basis of historical documents, by regression of cropland areas from LPA (2008) against cropland areas from CSMR (1923). We finally obtained the cropland area of each county in the Songnen Plain in 1908 (Table 1). The total area of cropland was about 49175.98 km^2 in 1908. Zhang *et al.* (2014) introduced the design step and concrete process making it possible to retrieve cropland area.

Table 1 Cropland area (km^2) of each county in the Songnen Plain in the late Qing Dynasty (1908)

County	Area	County	Area	County	Area	County	Area
Hailun	5043.00	Changling	2198.51	Huaide	2381.91	Mulan	530.84
Dehui	4035.59	Hulan	2180.84	Yitong	1214.34	Tangyuan	265.42
Changchun	3538.94	Suihua	2087.98	Kaitong	1159.68	Nehe	176.95
Binzhou	2927.03	Xincheng	1821.08	Wuchang	1069.06	Anda	60.65
Yushu	2775.49	Lanxi	1602.72	Anguang	926.96	Nenjiang	30.79
Nongan	2770.65	Yuqing	1494.73	Dalai	912.20	Zhaozhou	26.54
Shuangcheng	2390.08	Jing'an	1451.42	Longjiang	814.36	Guoqianqi	—
Bayan	2300.59	Taonan	1405.50	Baiquan	582.15	Acheng	—
Xingdong	—	Binjiang	—			Total	49175.98

3.2 Allocation of cropland area to grid cells

There is a noticeable correlation between historical population and agricultural development (Zhu *et al.*, 2012; Ye *et al.*, 2009). The history of agricultural exploitation demonstrates that

people always cultivate land that is flat and fertile, rather than land with complicated shapes, steep slopes and poor soil fertility (Li *et al.*, 2011). Water is the prerequisite for human survival. This paper therefore assumes that the agricultural suitability index (ASI) is closely related to settlements, water sources and topography. The ASI is quantified as in Eq. (1):

$$R = \frac{1}{a\alpha + b\beta + c\gamma} \quad (1)$$

where R is the ASI and α , β and γ represent the human dimension factor (settlements), the water resource factor and the topography complexity factor, respectively. A higher value of ASI indicates greater agricultural development, and vice versa.

To determine a , b and c , we used the broadly accepted analytical hierarchy process (AHP) method. This is a useful method for complex decision making (Xu, 2009). We used a decision scale of 2, calculated the value of the weight of each index, through the consistency examination. As a consequence, Eq. (1) can be given as:

$$R = \frac{1}{0.490\alpha + 0.312\beta + 0.198\gamma} \quad (2)$$

The spatial distribution of settlements in Heilongjiang province was taken from the 8th volume of the *Atlas of Historical Geography* (Tan, 1987); the spatial distribution of settlements in Jilin province was taken from Zeng *et al.* (2011). The spatial distribution of water resources (rivers) was taken from the National Geomatics Center of China. The surface elevation data were taken from the Bureau of Survey and Geo-information of Heilongjiang and Jilin Province (at 90 m \times 90 m resolution).

Figure 2 shows the spatial distribution of ASI of land for agricultural development at a cell size of 1 km \times 1 km in the Songnen Plain in the late Qing Dynasty.

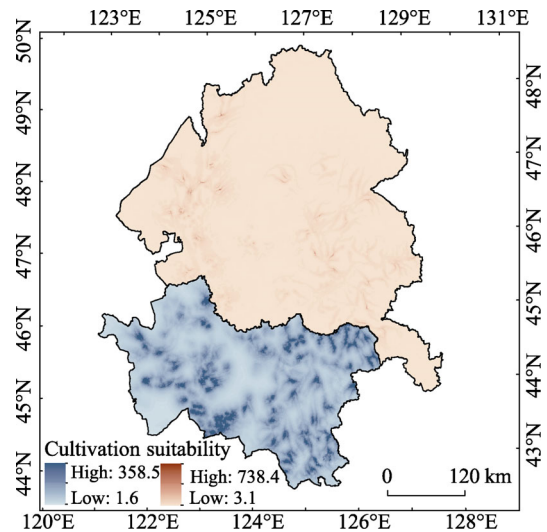


Figure 2 Spatial distribution of ASI of the Songnen Plain in the late Qing Dynasty (1908)

4 Results

4.1 Reconstruction of cropland based on method I

Historical documents generally record cropland area at county level. As administrative boundaries significantly changed over the last century, it is necessary to locate the historical records in the contemporary counties (Ye *et al.*, 2006). Figure 3 shows the distribution of the counties of the Songnen Plain in the late Qing Dynasty, based on the *New Area Map of the Republic of China* (Tong, 1917). Then, we quantified the potential area of cultivation, excluding forests, wetlands, rivers, lakes and mountains (Figure 4). We defined mountains as elevations higher than 200 m and slopes greater than 3°. The map of forest distribution in

1896 was taken from the *Map of Forest in Heilongjiang Province* (Li, 1993); the map of wetlands and lake distribution in the 1950s was taken from the *Map of Land Use in North-east China*, which was produced by the Economics Section of the Institute of Geography (Sun, 1959).

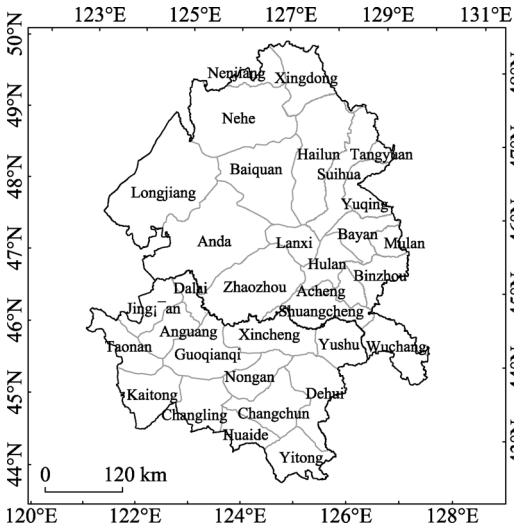


Figure 3 Administrative divisions in the Songnen Plain in the late Qing Dynasty

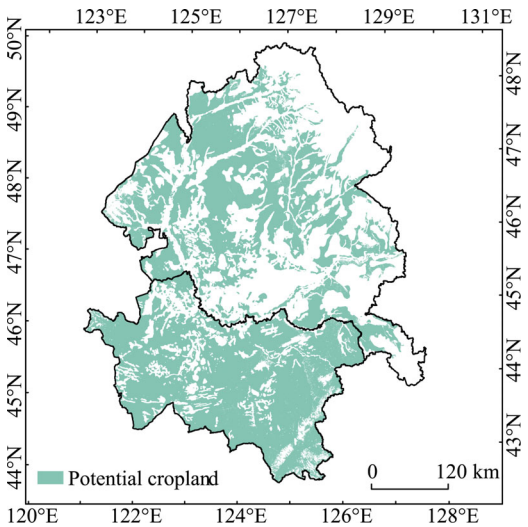


Figure 4 Potential cropland area of the Songnen Plain in the late Qing Dynasty

Finally, we quantified agricultural suitability just within the potential area. Following the order of the ASI from high to low, we assigned the area of cropland cell by cell. The process continued until all the cropland area had been allocated. Figure 5 shows the reconstructed spatially precise area of cropland in 1908 identified by method I.

4.2 Reconstruction of cropland based on method II

Method II was based on the reasonable assumption that historical cropland was located in the domain of the present cropland area (Li *et al.*, 2011). This assumption derived from the fact that cropland area has constantly increased over the past 300 years. In this study, we used spatial data on arable land resources in 1959 as potential cropland area. We used the spatial analysis function of ArcGIS to extract the spatial distribution of cropland from the *Map of Land Use in Northeast China* (Sun, 1959), which has a scale of 1:300,000 (Figure 6). These 1959 cropland data are some years away from the most recent information on the late Qing Dynasty that can be obtained. We then quantified agricultural suitability

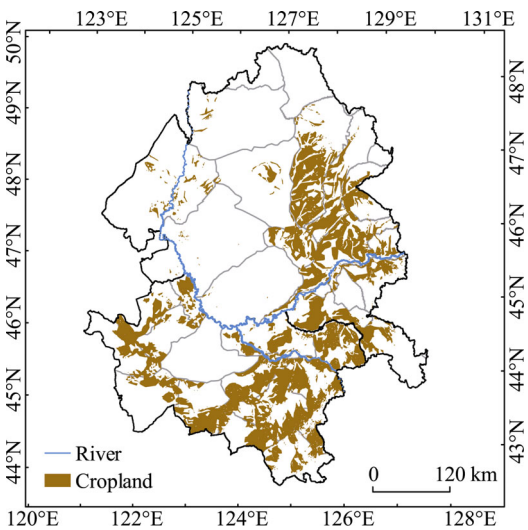


Figure 5 Spatial distribution of cropland in the Songnen Plain in 1908 reconstructed by allocating cropland within the potential cropland area

within the spatial distribution of cropland in 1959. The detailed calculation process was virtually identical to that of method I. Figure 7 shows the results for spatial distribution of cropland in the Songnen Plain in 1908 found with method II.

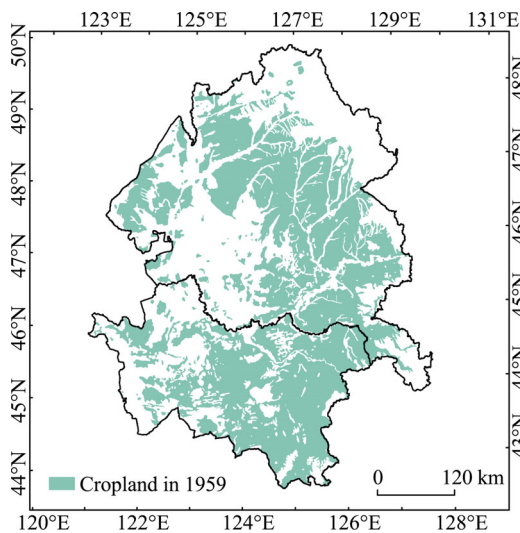


Figure 6 Spatial distribution of cropland in the Songnen Plain in 1959

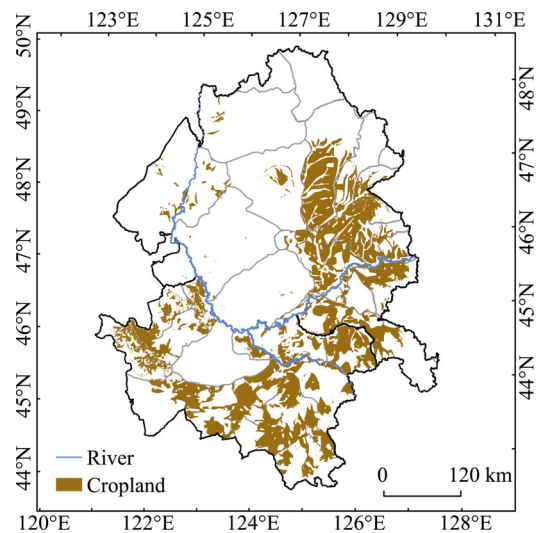


Figure 7 Spatial distribution of cropland in the Songnen Plain in 1908 reconstructed by allocating cropland within the cropland area in 1959

4.3 Comparison of the two methods of reconstructing cropland

By overlaying the analysis of the layer of cropland spatial patterns found with method I (Figure 5) and found with method II (Figure 7) in ArcGIS, the similarities and differences of cropland spatial patterns yielded by the two methods are thus made apparent (Figure 8). In Figure 8, brown represents matched cropland reconstructed by the two different methods; pink and blue represent unmatched cropland reconstructed by method I and method II, respectively. It can be seen that the cropland spatial distribution reconstructed using the two methods exhibits a similar spatial pattern. The regions where the two methods matched cover an area of 33,428 km² (about 68% of the total cropland area). Moreover, both of the methods show that the cropland lay mostly in the southern and eastern parts of the Songnen Plain in 1908.

As much of the research shows, the process of formation and evolution of ancient settlements (historic towns and villages) was closely related to agricultural

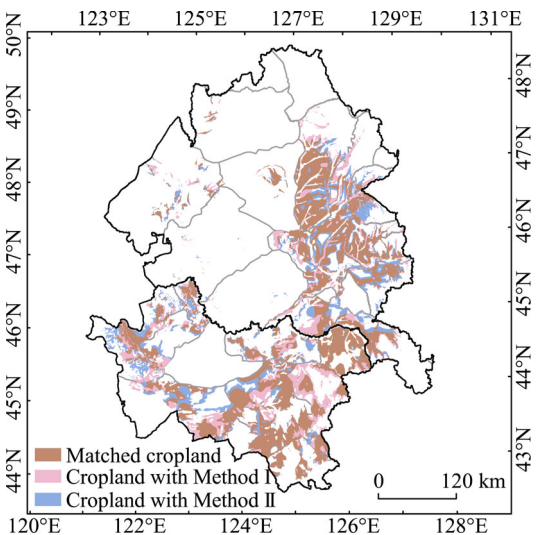


Figure 8 Spatial distribution of the unmatched cropland pixels in the Songnen Plain for late Qing Dynasty (1908) reconstructed using the two different methods

reclamation (Ye *et al.*, 2009; Lin *et al.*, 2008; Zeng *et al.*, 2011). Cropland spatial patterns were reconstructed using two methods in this paper, with the accuracy of this being verified by reference to settlements. This paper holds that the less distance there is between settlements and unmatched cropland spatial patterns, the more accurate a method is. Figure 9 shows the spatial distribution of settlements in the Songnen Plain in the late Qing Dynasty and the mismatch of cropland reconstructed by each method. However, it is not possible to tell which method is better just by studying Figure 9. Therefore, we calculated the average coordinates of settlements and average coordinates of unmatched cropland pixels of two reconstructions for each county in the Songnen Plain, and compared their accuracy and efficiency (Table 2). Table 2 indicates that the distance between the average coordinates of

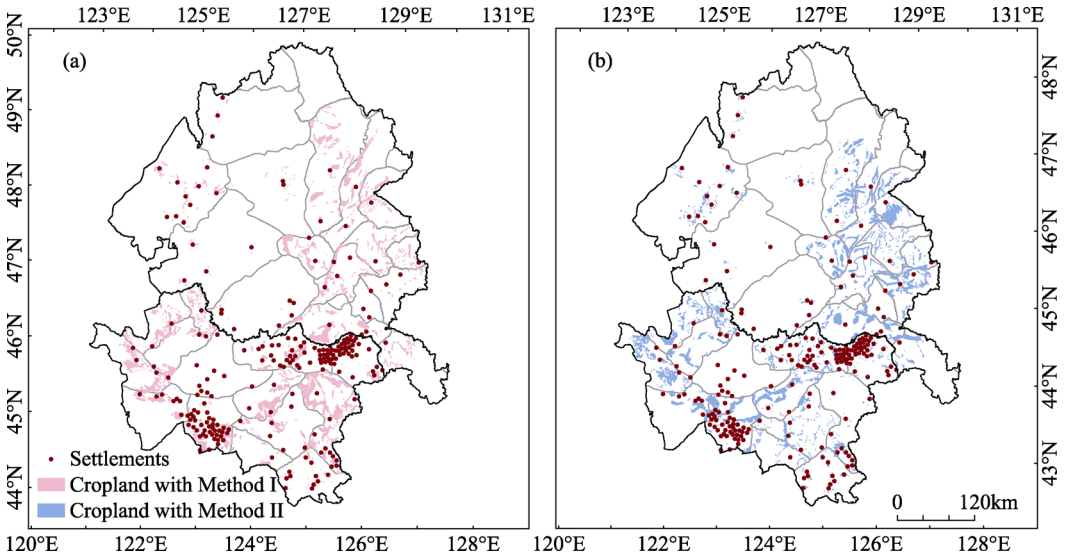


Figure 9 Spatial distribution of settlements in the Songnen Plain for the late Qing Dynasty and mismatch of cropland pixels reconstructed (a) by allocating cropland area within the potential cropland area and (b) by allocating cropland area within cropland area in 1959

Table 2 Average coordinates of settlements and average coordinates of unmatched cropland pixels of two reconstructions for each county in the Songnen Plain (°E,°N)

County	Settlement	Method I	Method II	County	Settlement	Method I	Method II
Wuchang	127.1, 44.8	127.3, 44.8	127.4, 44.9	Longjiang	124.0, 47.5	124.0, 47.5	124.1, 47.5
Yuqing	127.5, 46.9	127.7, 46.9	127.5, 46.9	Yitong	125.2, 43.5	125.2, 43.5	125.2, 43.5
Lanxi	126.2, 46.3	127.7, 46.9	127.5, 46.9	Nongan	124.7, 44.6	124.9, 44.7	125.1, 44.7
Shuangcheng	126.6, 45.3	126.4, 45.4	126.3, 45.4	Dalai	123.9, 45.8	123.8, 45.9	123.8, 45.9
Hulan	126.6, 46.1	126.8, 46.0	126.7, 45.9	Anguang	123.3, 45.5	123.3, 45.5	123.3, 45.5
Anda	124.2, 46.6	124.3, 46.7	124.0, 46.6	Kaitong	122.9, 44.8	123.0, 44.9	122.7, 44.9
Binzhou	127.5, 45.8	127.6, 45.7	127.7, 45.8	Dehui	125.8, 43.9	125.7, 43.9	125.9, 44.1
Bayan	127.4, 46.1	127.4, 46.3	127.6, 46.3	Huaide	124.6, 43.8	124.4, 44.0	124.3, 44.0
Baiquan	125.9, 47.4	126.0, 47.5	125.7, 44.4	Xincheng	125.6, 45.1	125.3, 45.1	125.3, 45.1
Mulan	128.2, 46.0	127.9, 46.1	127.9, 46.1	Yushu	126.5, 45.0	126.6, 45.0	126.6, 44.8
Hailun	126.7, 47.1	126.8, 47.2	128.0, 47.6	Taonan	122.7, 45.4	122.5, 45.4	122.6, 45.3
Suihua	127.1, 46.9	127.0, 46.8	127.2, 47.1	Changling	123.6, 44.4	123.6, 44.4	123.5, 44.4
Zhaozhou	125.0, 45.7	125.5, 45.8	124.7, 45.9	Changchun	124.9, 44.2	125.0, 44.2	124.8, 44.3
Nehe	124.9, 48.5	124.9, 48.4	125.0, 48.4	Jing'an	122.8, 45.7	123.2, 45.9	122.9, 45.8
Acheng	127.0, 45.6	126.9, 45.8	127.0, 45.7	Average	125.5, 45.7	125.5, 45.7	125.5, 45.8

settlements and unmatched cropland pixels of method I is closer than that of method II, in most counties. In view of the arguments set out above, we can safely conclude that reconstruction using method I may have less bias than that using method II.

5 Conclusions

This paper reconstructed spatially precise areas of cropland in the Songnen Plain in the late Qing Dynasty using two methods. We compared the results obtained from the two methods. The major conclusions are as follows:

(1) Analysis of these two methods yielded approximately the same results as the cropland spatial patterns. Agricultural development mostly occurred in the eastern and southern parts of the Songnen Plain. Other areas, especially the northern and western parts of the study area, were less developed. The total area of cropland in the Songnen Plain was 49,175.95 km² in 1908. Both methods matched each other for about 68% of the total cropland area. No evident regularity was found in the area where the two methods did not match.

(2) By spatially comparing the unmatched cropland pixels of the two methods with the settlements for each county, this study found that the unmatched cropland pixels yielded by method I were closer to settlements than those yielded by method II. The results indicate that reconstruction with method I may have less bias than that with method II.

6 Discussion

(1) Most recent research has reconstructed historical cropland distribution using method II because historical data were scarce. Thus the accuracy of the results may be reduced. It is therefore suggested that historical cropland distribution should be reconstructed using method I. Method I is generally applicable, and the prediction results will be more accurate if there are sufficient historical data.

(2) Three datasets provide spatially precise cropland data for the Songnen Plain in the late Qing Dynasty: SAGE, HYDE and CNEC. However, the quality of the SAGE and HYDE datasets is poor in Northeast China (Li *et al.*, 2010). Therefore, we did not further compare the results of this study with the HYDE and SAGE datasets.

The CNEC dataset (Ye *et al.*, 2009) has reconstructed the spatial distribution of cropland at the county level, based on the present county boundaries. To compare our results with those of CNEC, we recalculate the fraction of cropland area at the county level based on the present counties, using our reconstructed data with each of the two methods. Table 3 indicates that our estimations with method I and method II are in the same range as that of CNEC for 34 and 28 counties, respectively, and about 67% and 55% of the total number of counties, accordingly. This further confirms that our results with the two methods are convincing, and that spatially explicit reconstruction of cropland with method I is more accurate than that with method II.

(3) The administrative boundaries of the Songnen Plain have changed since the late Qing Dynasty. This paper reconstructed the administrative boundaries of the Songnen Plain in the late Qing Dynasty, and in some areas, this could produce a smaller real cropland area than that found in historical documents. In this study, the potential cultivation area was estimated

Table 3 Cropland area fraction in 1908 for each modern county

County	R ₁	R ₂	R ₃	County	R ₁	R ₂	R ₃	County	R ₁	R ₂	R ₃
Nongan	0.60	0.47	0.6–1	Bayan	0.63	0.63	0.1–0.2	Lindian	0.00	0.00	0–0.05
Beian	0.07	0.02	0.2–0.6	Hulan	0.52	0.52	0.1–0.2	Tailai	0.01	0.00	0–0.05
Hailun	0.58	0.60	0.2–0.6	Shuangcheng	0.46	0.43	0.1–0.2	Zhenlai	0.29	0.27	0–0.05
Suiling	0.20	0.13	0.2–0.6	Wuchang	0.20	0.24	0.1–0.2	Zhaoyuan	0.03	0.01	0–0.05
Qing'an	0.21	0.28	0.2–0.6	Gannan	0.03	0.01	0.05–0.1	Anda	0.05	0.00	0–0.05
Wangkui	0.60	0.77	0.2–0.6	Longjiang	0.01	0.01	0.05–0.1	Zhaodong	0.10	0.09	0–0.05
Lanxi	0.46	0.53	0.2–0.6	Fuyu	0.09	0.08	0.05–0.1	Zhaozhou	0.00	0.01	0–0.05
Suihua	0.49	0.60	0.2–0.6	Taonan	0.35	0.37	0.05–0.1	Acheng	0.03	0.07	0–0.05
Mulan	0.26	0.24	0.2–0.6	Qian'an	0.05	0.08	0.05–0.1	Binxian	0.31	0.51	0–0.05
Da'an	0.09	0.09	0.2–0.6	Qianguo	0.28	0.40	0.05–0.1	Tongyu	0.18	0.18	0–0.05
Fuyu	0.25	0.23	0.2–0.6	Changling	0.51	0.41	0.05–0.1	Daqing	0.00	0.00	0–0.05
Yushu	0.57	0.56	0.2–0.6	Nehe	0.03	0.03	0–0.05	Baicheng	0.36	0.50	0–0.05
Dehui	0.52	0.26	0.2–0.6	Keshan	0.00	0.00	0–0.05	Gongzhuling	0.50	0.52	0.2–0.6
Jiutai	0.48	0.03	0.2–0.6	Kedong	0.00	0.00	0–0.05	Harbin	0.26	0.28	0–0.05
Changchun	0.52	0.48	0.2–0.6	Yian	0.00	0.00	0–0.05	Qiqihar	0.06	0.09	0.05–0.1
Yitong	0.14	0.14	0.2–0.6	Baiquan	0.12	0.13	0–0.05	Dorbot	0.01	0.00	0–0.05
Qinggang	0.15	0.14	0.1–0.2	Mingshui	0.03	0.03	0–0.05	Wudalianchi	0.00	0.00	0–0.05

Note: R₁ stands for the results of method I; R₂ stands for the results of method II; R₃ stands for the results of CNEC

by excluding forests, wetlands, rivers, lakes and mountains. As these geographical features did not co-occur temporally with the historical cropland, there may be some uncertainty regarding the estimated area of cultivation. It should be noted that '2' was used as the decision scale in the AHP model. This value still requires further verification.

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