

Determination of land salinization causes via land cover and hydrological process change detection in a typical part of Songnen Plain

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Abstract: Causes of land salinization were determined via land cover and hydrological process change detection in a typical part of Songnen Plain. The area of saline land increased from 4627 km² in 1980 to 5416 km² in 2000, and then decreased to 5198 km² in 2015. The transformation between saline land and other land covers happened mainly before 2000, and saline land had transformation relationship mainly with cropland, grassland, and water body. From 1979 to 2007, groundwater depth fluctuated to increase and was mainly deeper than 3.3 m. Spatially, the area of the region where groundwater depth was deeper than 3.3 m increased from 46.7% in 1980 to 84% in 2000, while the area of the region almost occupied the whole region after 2000. Precipitation and evaporation changed little, while runoff decreased substantially. Shallow groundwater, change of cropland, grassland, and water body induced from human activities and decrease of runoff and increase of irrigation and water transfer from outer basin were the main reasons for land salinization before 2000. After 2000, groundwater with relatively great depth could not exert great influence on land salinization. Protection of grassland and wetland prevented the increase of the area of saline land.

Keywords: change detection; hydrological process; land cover; land salinization; Songnen Plain

1 Introduction

Land salinization is one of the most common land degradation processes (UNEP, 1991). More than 77 m ha (million hectares) of land were salt-affected and about 43 m ha were attributed to secondary salinization at global scale in 2007 (FAO, 2007). Moreover, some estimates indicated that one-third of the irrigated land in the major countries with irrigated agriculture was badly affected by salinity or expected to be salinized in the near future (Lambert *et al.*, 2002; Akhtar *et al.*, 2013). Land salinization often occurs particularly in arid

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or semiarid areas (Masoud and Koike, 2006), where low rainfall, high evapotranspiration rates or soil textural characteristics impede the washing out of the salts which subsequently built-up in the soil surface layers. Threats of land salinization on ecosystem and environment are obvious (Line *et al.*, 2010). Accumulation of soluble salts in the soil is one of the main limiting factors for agriculture by decreasing the soil productivity (Rengasamy, 2002), limiting the growth of crops (Datta *et al.*, 2002; Yamaguchi and Blumwald, 2005), constraining agricultural productivity (Qadir *et al.*, 2008) and even leading to the abandonment of arable lands (Ding *et al.*, 2011). Besides, it also poses threats on environment by increasing the salinity of water, decreasing biodiversity of ecosystem (Halse *et al.*, 2003), and affecting other major soil degradation phenomena such as soil dispersion, soil erosion (García-Ruiz, 2010), and engineering problems (Metternicht and Zinck, 2003). Given these adverse impacts, detecting its causes is important for better management practices.

Songnen Plain, which is the largest production base of commodity grain in China, has 3.2 m ha saline land (21% of the area of the Plain) (Wang *et al.*, 2009) and is the biggest distribution area of soda saline land in China (Gu, 2010). Many reasons resulted in the occurrence of the land salinization of Songnen Plain. Neo-plate tectonics provided the sources and transport path, and generated the accumulation environment (Wang *et al.*, 1985). Shallow depth groundwater provided the solvent and carrier for the dissolving and rise of the soil salt (Song *et al.*, 2000; Zhang *et al.*, 2000). Arid or semiarid climate provided the power for the rise of the water and salt in the soil profile (Yu *et al.*, 1993; Liu *et al.*, 2002). In the last several decades, land salinization has been aggravated constantly. Human activities, which lead to the changes of the hydrological process, are the main driving factors to the soil salinization (Liu *et al.*, 2005). Moreover, shallow depth groundwater and ponding rainwater lead to the primary land salinization, while the secondary land salinization was induced from the significant decrease of the chances and occurrence frequency of flooding and waterlogging in the low-lying plains (Yang *et al.*, 2010). Even many researches had paid attention to saline land of Songnen Plain, the detailed spatio-temporal transformation relationship with other land covers and long-term hydrological process, especially, the spatio-temporal distribution of groundwater were not depicted at the same time. In this study, a typical part of Songnen Plain was chosen to analyze its causes for land salinization by revealing the spatio-temporal change of land covers and hydrological process simultaneously.

2 Study area

Land salinization, which mainly distributed in the western part, was a severe problem in Songnen Plain. This part including 5 counties where land salinization problem was typical was chosen as the study area (Figure 1). The area of the typical part was 25,664 km². The terrain decreased from Northwest to Southeast and the altitude of the whole part was mainly from 100 to 200 m. The Taoer River flows through this part and runs toward Nenjiang River. The flat terrain made the precipitation and runoff from the upper reach accumulated in this area and evaporation was the main means of discharge. High evaporation (1194 mm, Φ20 cm pan evaporation), low precipitation (386 mm), and a large amount of irrigation created a favorable condition for the aggregation of soil salt on the land surface.

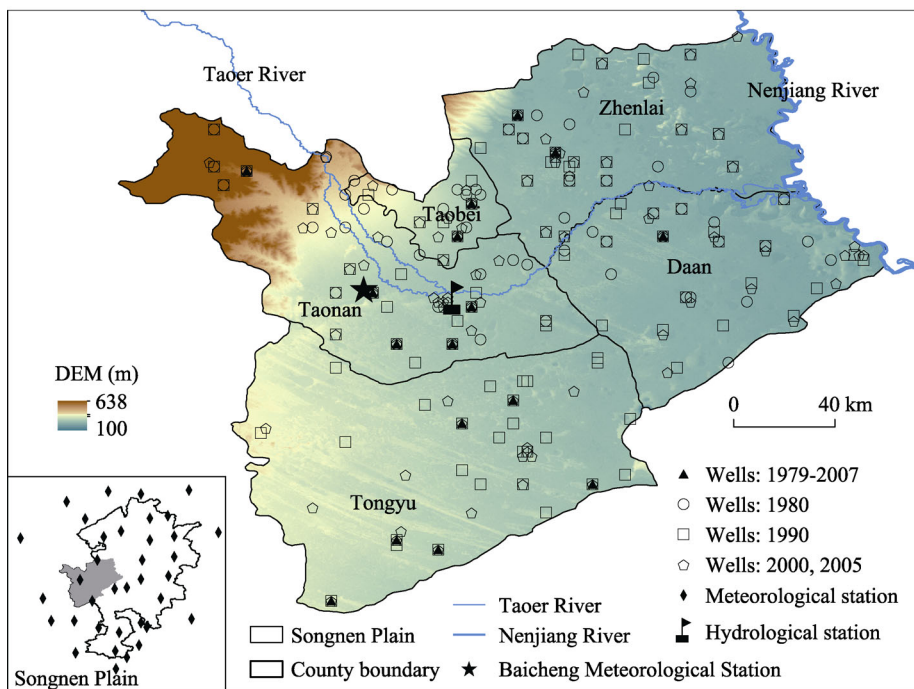


Figure 1 Location of the typical part of Songnen Plain

3 Data and methods

3.1 Land cover database

Six land cover databases, with a mapping scale of 1:1,000,000, of the years 1980, 1990, 2000, 2005, 2010, and 2015 were collected from ‘Data Center for Resources and Environmental Sciences Chinese Academy of Sciences’ (website: <http://www.resdc.cn/Default.aspx>). The data source for the land cover database was Landsat MSS/TM/ETM/OLI, China-Brazil Earth Resources Satellite, Small Satellite Constellation for Environment and Disaster Monitoring, and Forecasting HJ-1 satellite digital images (Liu *et al.*, 2014; Liu *et al.*, 2015). More detailed information about this land cover database could be found in previous reports (Liu *et al.*, 2010).

In this paper, based on the classified 25 second-level land cover types, the land cover data were grouped into seven classes: cropland, woodland, grassland, water body (including swampland), built-up area, unused land, and saline land to reveal the spatio-temporal dynamic of the saline land.

3.2 Hydrological data

Hydrological data included groundwater depth, precipitation, evaporation, and runoff.

Groundwater depth collected from the ‘Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences’. The data included the groundwater depth every 5 days from 16 wells from 1979 to 2007, annual mean groundwater depth every 5 days from 61 wells in 1980, annual mean groundwater depth every 5 days from 98 wells in 1990, annual mean

groundwater depth every 5 days from 86 wells in 2000 and 2005. The data from 1979 to 2007 were used for analyzing the temporal variation of groundwater depth. The data in 1980, 1990, 2000, and 2005 were used for analyzing the spatial distribution of groundwater depth based on the spatial interpolation by using the Kriging interpolation method. The spatial distribution of groundwater depth in 2010 and 2015 was also analyzed based on “Monthly report of groundwater dynamics”, which was opened for inquiry at website (<http://www.hydroinfo.gov.cn/>).

Annual precipitation and evaporation from 1960 to 2015 were collected from Baicheng Meteorological Station for the temporal variation analysis. Runoff from 1983 to 2006 at Taonan Hydrological Station was collected for the temporal variation analysis. Spatial interpolation data of precipitation in 1980, 1990, 2000, 2005, 2010, and 2015 were collected for the analysis of spatial distribution. The dataset is provided by Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) (<http://www.resdc.cn>). Data on annual pan evaporation ($\Phi 20$ cm) of Songnen Plain in 1980, 1990, 2000, 2005, 2010, and 2015 at 36 meteorological stations were collected for spatial interpolation by using the Spline method. Spatial distribution in the typical area was cut out from the whole area for spatial dynamic analysis.

3.3 Transfer matrix

Land cover transfer matrix was used for the analysis of transformation between saline land and other kinds of land covers. Details about this method could be found from previous studies (Lai *et al.*, 2014; Li *et al.*, 2016).

3.4 Gravity

Gravity was the geographic center that was defined as a point constructed from the average longitude and latitude weighted by the area of a particular kind of land cover patch individually. Gravity represented its spatial distribution center. The change of the gravities' location showed the change of the spatial distribution of a particular kind of land cover. Gravity was used to represent the spatial distribution center of saline land in this study.

The expression for Gravity calculation was listed as following:

$$\begin{aligned} X_t &= \sum_{i=1}^N C_{ti} \times X_i / \sum_{i=1}^N C_{ti} \\ Y_t &= \sum_{i=1}^N C_{ti} \times Y_i / \sum_{i=1}^N C_{ti} \end{aligned} \quad (1)$$

where X_t and Y_t are the longitude and latitude of a particular land cover in the year t ; C_{ti} is the area of the number i patch of the particular land cover in the year t ; X_i and Y_i are the longitude and latitude of the number i patch for the particular land cover. Gravities of saline land and water body were calculated by using the spatial analysis software Arcgis 10.2.

4 Results

4.1 Spatio-temporal change of saline land area

In the typical part of Songnen Plain, cropland, grassland, saline land, and water body were the major land covers. From 1980 to 2015, the mean area of saline land was 5170 km² (Table 1).

The area of saline land increased from 4627 km² in 1980 to 5416 km² in 2000, and then decreased to 5198 km² in 2015. Most of the region was occupied by saline land except for the built-up area in Taobei and the riversides of Taoer and Nenjiang rivers (Figure 2). Saline land almost occupied the southeast part of the whole area. The spatial distribution centers have the almost similar location with the spatial center of the whole area (Figure 2). All of this indicated that the saline land distributed uniformly in the study area. The distribution center moved from Northwest to Southeast when the area of saline land increased. In the 5 counties, Da'an was the major distribution region. The bigger the area of saline land, the closer to Da'an the distribution center. The change of saline land in Da'an was the major reason for the change of spatial distribution.

Table 1 Area of land covers in the typical part of Songnen Plain (km²)

Year	Cropland	Woodland	Grassland	Water body	Built-up land	Unused land	Saline land
1980	9259	572	6447	3769	531	459	4627
1990	9382	388	5856	3845	552	504	5137
2000	11816	1205	3325	3185	567	150	5416
2005	12003	1194	3363	3067	565	150	5322
2010	11983	1193	3363	3066	586	150	5323
2015	13278	1202	3327	1896	613	150	5198

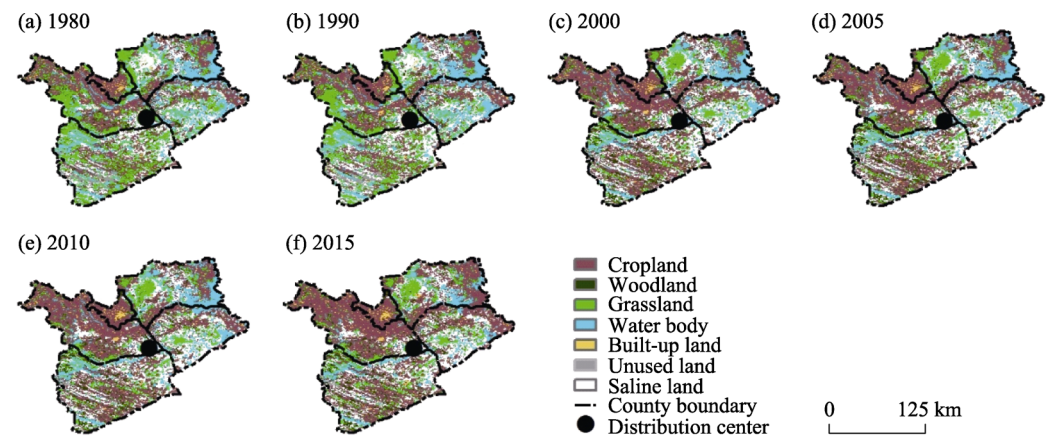


Figure 2 Land covers of the typical part of Songnen Plain

4.2 Transformation of saline land

Transformation among different land covers was calculated (Table 2). From 1980 to 1990, saline land transformed mostly from grassland (1044 km²), cropland (831 km²), and water body (408 km²) into cropland (704 km²), grassland (627 km²), and water body (477 km²). From 1990 to 2000, saline land transformed mostly from grassland (965 km²), cropland (831 km²) and water body (704 km²) into cropland (1026 km²), grassland (768 km²) and water body (379 km²). In the periods of 2000 to 2005, 2005 to 2010, and 2010 to 2015, the transformation between saline land and other land covers was slight. Generally, before 2000, saline land transformed from cropland, grassland, and water body dramatically, but after 2000, there was almost no transformation between saline land and other land covers.

Table 2 Transfer matrix of land covers in the typical part of Songnen Plain (km²)

		Cropland	Woodland	Grassland	Water body	Built-up land	Unused land	Saline land	Total
1990									
1980	Cropland	6521	130	1016	419	291	51	831	9259
	Woodland	203	126	135	27	6	8	67	572
	Grassland	1125	69	3595	450	78	86	1044	6447
	Water body	472	16	372	2439	28	34	408	3769
	Built-up land	295	4	62	23	74	12	61	531
	Unused land	62	7	49	10	5	247	79	459
	Saline land	704	36	627	477	70	66	2647	4627
	Total	9382	388	5856	3845	552	504	5137	25664
2000									
1990	Cropland	7022	366	478	364	308	13	831	9382
	Woodland	168	132	37	11	4	1	35	388
	Grassland	2333	432	1625	380	67	54	965	5856
	Water body	705	54	336	2016	26	4	704	3845
	Built-up land	319	16	50	19	82	1	65	552
	Unused land	243	55	31	16	12	55	92	504
	Saline land	1026	150	768	379	68	22	2724	5137
	Total	11816	1205	3325	3185	567	150	5416	25664
2005									
2000	Cropland	11765	5	19	10	1	0	16	11816
	Woodland	14	1187	3	0	0	0	1	1205
	Grassland	56	1	3221	8	0	0	39	3325
	Water body	121	0	19	3008	0	0	37	3185
	Built-up land	3	0	0	0	564	0	0	567
	Unused land	0	0	0	0	0	150	0	150
	Saline land	44	1	101	41	0	0	5229	5416
	Total	12003	1194	3363	3067	565	150	5322	25664
2010									
2005	Cropland	11974	0	5	0	23	0	2	12003
	Woodland	1	1193	0	0	0	0	0	1194
	Grassland	5	0	3358	0	0	0	0	3363
	Water body	1	0	0	3066	0	0	0	3067
	Built-up land	2	0	0	0	563	0	0	565
	Unused land	0	0	0	0	0	150	0	150
	Saline land	1	0	0	0	0	0	5321	5322
	Total	11983	1193	3363	3066	586	150	5323	25664

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(Continued)

		Cropland	Woodland	Grassland	Water body	Built-up land	Unused land	Saline land	Total
2015									
2010	Cropland	11874	26	21	14	23	0	25	11983
	Woodland	17	1173	1	0	2	0	0	1193
	Grassland	88	0	3261	4	3	0	7	3363
	Water body	1162	2	11	1867	1	0	23	3066
	Built-up land	20	0	1	0	565	0	0	586
	Unused land	0	0	0	0	1	149	0	150
	Saline land	117	1	32	11	18	1	5143	5323
	Total	13278	1202	3327	1896	613	150	5198	25664

4.3 Change of hydrological process

From 1979 to 2007, groundwater depth of the 16 wells was almost greater than 1.7 m and mainly greater than 3.3 m (Table 3 and Figure 3). In the 16 wells, there were 15 wells that the ratio between the data number which was larger than 1.7 m and the whole data number was bigger than 80%. There were 8 wells that ratio between the data number which was larger than 3.3 m was bigger than 70% (Table 3). The groundwater depth had a relatively regular seasonal pattern that the groundwater rose in spring, dropped down in summer with fluctuation, and rose again in autumn and winter (Figure 3). In the long run, from 1979 to 2007, the groundwater depth of 13 wells had an increasing trend and the groundwater depth changed with fluctuation in the other 3 wells.

Groundwater depth was larger than 3.3 m in the most part of the whole area (Figure 5). In 1980, groundwater depth was mainly less than 1.7 m (27%) and larger than 3.3 m (46.7%). In 1990, groundwater depth was mainly 2.4–3 m (14.5%) and larger than 3.3 m (65%). In 2000 and 2005, groundwater depth was mainly larger than 3.3 m, and the area ratio was 84% and 99.9%, respectively. As shown in the “Monthly report of groundwater dynamic”, groundwater depth was mainly larger than 4 m and was 2–4 m in a relatively small part from 2010 to 2015. The area of the region where the groundwater depth was larger than 3.3 m increased to the whole region from 1980 to 2005 and the groundwater level went down consistently from 2000 to 2015.

The precipitation and evaporation at Baicheng meteorological station did not show a significant changing trend with an approximately 40-year period. The mean precipitation and evaporation was 386 mm and 1194 mm, respectively (Figure 4). From 1983 to 2006, the runoff of Taonan hydrological station fluctuated to decrease, except for a deluge in 1998 and after 2000, the runoff decreased to be nearly exhausted. Precipitation showed no typical spatial distribution pattern (Figure 5). From 1980 to 2015, the spatial distribution pattern of precipitation changed a lot. Evaporation showed two kinds of spatial distribution pattern, thus decreased from Southwest to Northeast and decreased from Southeast to Northwest. From 1980 to 2015, the change of evaporation spatial distribution pattern was not dramatic with 1700–2100 mm in domination.

Table 3 Ratio between data number in typical groundwater depth interval and the whole data number in one well (%)

Well number	Groundwater depth						
	<1.7 m	1.7–2.0 m	2.0–2.2 m	2.2–2.4 m	2.4–3 m	3–3.3 m	>3.3 m
DA1	0	0.7	1.2	0.8	5.0	2.5	89.8
TB1	14.6	10.9	9.5	8.9	20.7	4.6	30.8
TB2	0	0	0	0	10.0	16.0	74.0
TN1	47.5	8.2	4.2	4.2	5.8	7.2	23.0
TN2	0	0	0	1.1	11.9	13.7	73.4
TN3	2.3	1.4	0	0	0	0	96.3
TN4	3.7	7.8	8.4	7.8	19.6	8.7	43.9
TN5	0	0	0.1	1.8	12.2	9.4	76.6
TY1	0	5.1	14.8	23.1	51.2	5.6	0.2
TY2	18.8	8.3	5.9	6.1	13.4	3.4	44.2
TY3	0	0	0	0	1.7	11.6	86.7
TY4	8.8	7.9	6.7	5.1	20.9	11.3	39.3
TY5	3.2	4.0	6.5	12.7	23.4	13.7	36.4
TY6	0	0	2.0	5.1	16.0	11.4	65.6
ZL1	0	0	0	0	0	0.4	99.6
ZL2	0.2	1.4	2.5	1.9	7.6	4.1	82.1

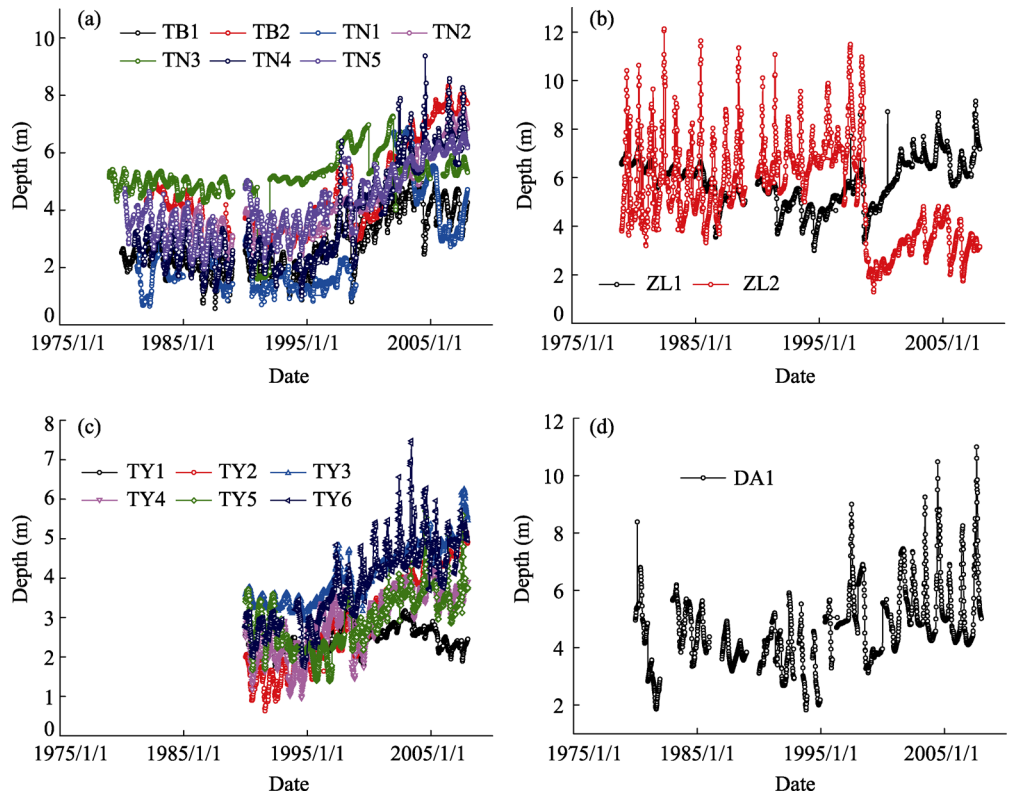


Figure 3 Temporal distribution of groundwater depth in the typical part of Songnen Plain

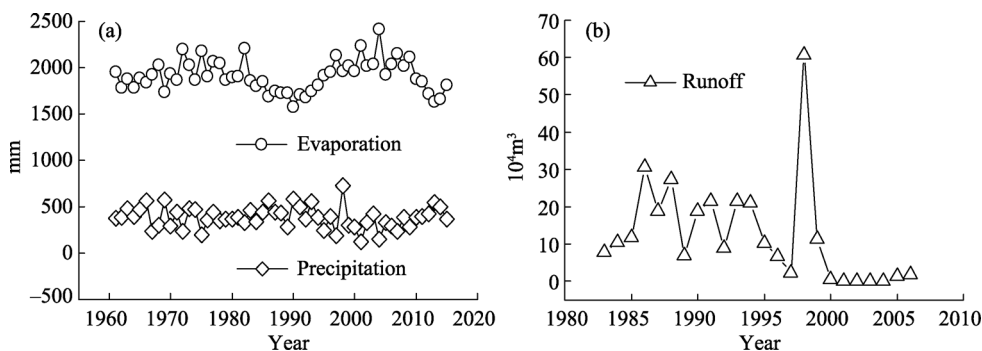


Figure 4 Temporal distribution of evaporation, precipitation and runoff in the typical part of Songnen Plain

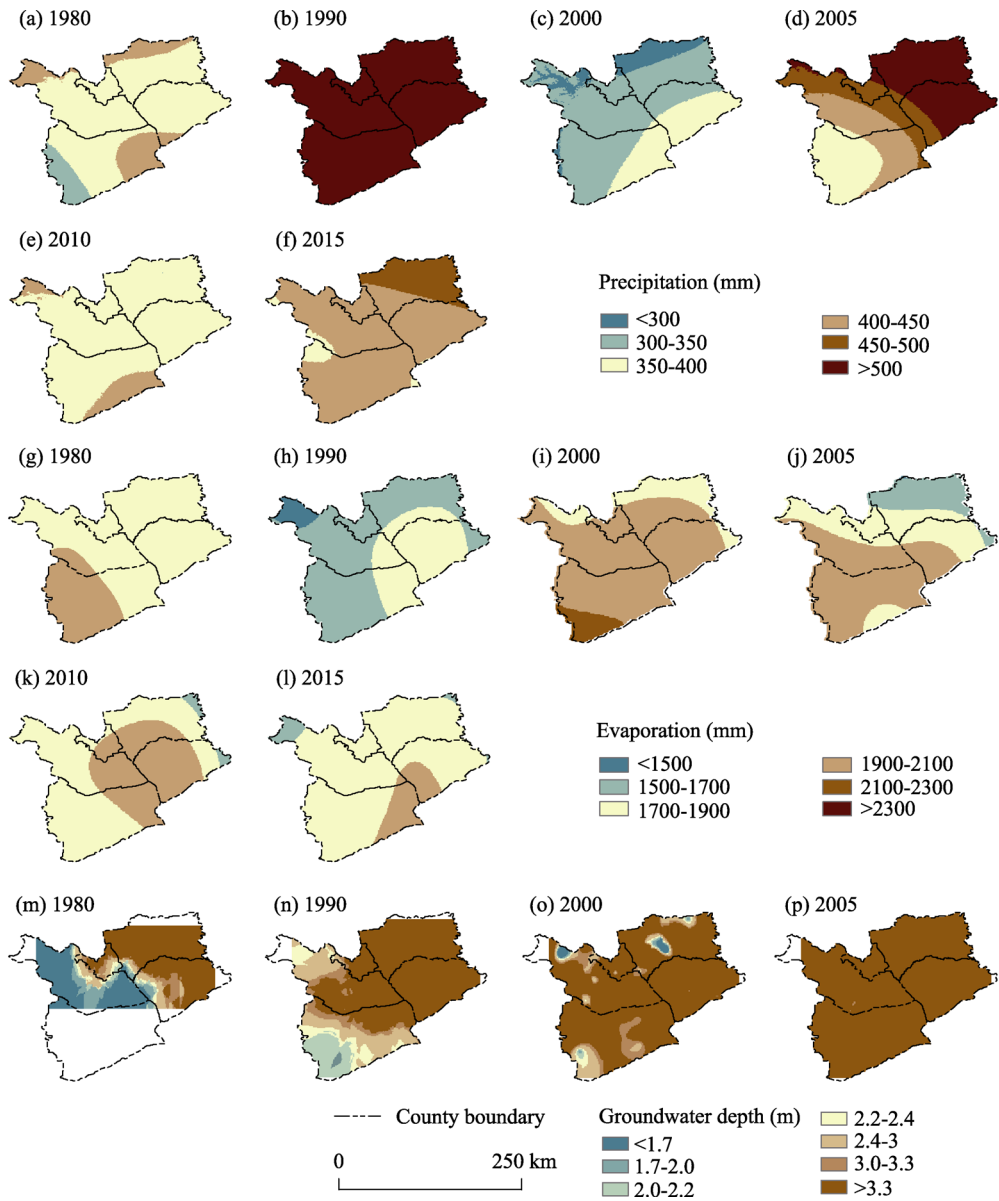


Figure 5 Spatial distribution of precipitation, evaporation and groundwater depth in the typical part of Songnen Plain

4.4 Causes of land salinization

Land salinization was the result of salt aggregation on land surface. Any factors which could exert influence on the salt aggregation in the upper soil layer, such as change of evaporation interface, accessibility to land surface of groundwater, and so on, may cause the change of land salinization. Causes of land salinization were determined from land cover change and hydrological process change.

4.4.1 Determination from land cover change

From 1980 to 2015, saline land had close transfer relationship with cropland, grassland, and water body. This meant that the factors that could exert influence on the change of cropland, grassland, and water body may exert influence on the change of saline land. Even cropland was mainly composed of dry land, the ratio between the area of paddy field and the area of cropland increased from 4.9% in 1980 to 12.7% in 2015. The increase of cropland included the increase of dry land and paddy field. From 1980 to 2015, the area of dry land increased from 8617 km² to 10319 km² (increased by 19.8%), while, the area of paddy field increased from 447 km² to 1502 km² (increased by 236%). The amount of water for irrigation mainly depended on the area of paddy field, so that the high speed increase of area of paddy field highly increased the irrigation amount which was the main reason for secondary land salinization.

Change of grassland was composed of change of high coverage grassland and middle coverage grassland. From 1980 to 2015, high coverage grassland decreased from 3672 km² to 1519 km² (decreased by 58.6%), and middle coverage grassland decreased from 2645 km² to 1760 km² (decreased by 33.5%), respectively. The change of area of grassland mainly happened in the period from 1980 to 2000. In this period, cropland, water body, and saline land were the major land cover transformation types. Grassland included high coverage grassland and middle coverage grassland. From 1980 to 2000, high coverage grassland mainly transformed into cropland and middle coverage grassland, middle coverage grassland mainly transformed into saline land, and low coverage grassland mainly transformed into saline land and dry land. Transformation from grassland to saline land was a direct reason for land salinization and transformation from grassland to cropland increased the risk of land salinization.

Change of water body referred to change of lake and flood plain. From 1980 to 2015, lake decreased from 1370 km² to 797 km² (decreased by 41.8%), and flood plain increased from 207 km² to 339 km² (increased by 63.8%), respectively. From 1980 to 2015, the areas of lake changed to paddy field, dry land, middle coverage grassland, flood plain, saline land, and swampland were 14 km², 103 km², 18 km², 122 km², 192 km², and 182 km², respectively, while, the area of flood plain changed to dry land was 11 km². The transformation from lake to saline land was a direct reason and transformation from lake or flood plain to shallow water area, middle coverage grassland, and dry land increased the risk of land salinization.

4.4.2 Determination from hydrological process change

Besides interface of water movement, change of water movement process was also a vital factor for land salinization. Rise of groundwater was a major reason of land salinization, so the completeness of rise to the ground surface was a necessary condition for evaporation. Based on the previous study in Songnen Plain (GSIJP, 2006) (Table 4), 3.3 m of the

groundwater depth was seen as a critical value that groundwater could cause land salinization. In the typical part of Songnen Plain, from 1979 to 2015, groundwater depth was larger than 3.3 m in most of the cases. The ratio between the area of the region where groundwater depth was larger than 3.3 m and the whole region increased from 46.7% in 1980 to 84% in 2000, and then increased from 92.6% in 2001 to 99.9% in 2005. The region where groundwater depth was larger than 3.3 m almost occupied the whole region steadily from 2005 to 2015. Before 2000, the relatively shallow groundwater was an important reason for land salinization, while, after 2000, the groundwater with relatively large depth was not a direct reason for land salinization.

Table 4 Groundwater depth threshold induced for soil salinization in Songnen Plain (Geological Survey Institute of Jilin Province, 2006)

Soil texture	Soil salinization level	Groundwater depth threshold (m)
Sandy loam	Non	>3.3
	Light	2.4–3.3
	Middle	2.0–2.4
	Heavy	<2.0
Clay loam	Non	>3.0
	Light	2.2–3.0
	Middle	1.7–2.2
	Heavy	<1.7

In the typical part of Songnen Plain, evaporation was bigger than precipitation. In this area, evaporation was the major discharge manner. With a large amount of cropland and insufficient precipitation and surface water runoff, irrigation, which came from deep groundwater, river, lake, and transferred water from outer basin, was an important water source for cropland. Reduction of surface water runoff and addition of irrigation produced a phenomenon that area of the region with long time waterlogging decreased and area of the region waterlogged temporarily increased. It increased the cycle of vertical leach and evaporation process, which was the key process of land salinization. The area of paddy field and flood plain increased by 1026 km² from 1980 to 2000, and then increased by 161 km² from 2000 to 2015 (Figure 6). The area of river, lake, water reservoir, and swampland decreased by 873

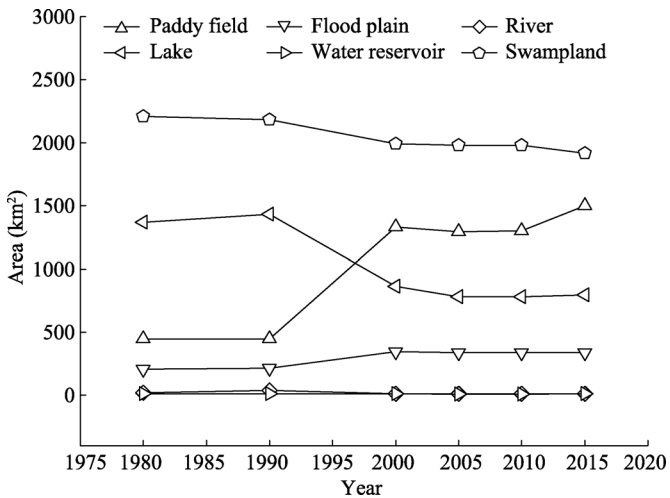


Figure 6 Change of area of region covered by water in the typical part of Songnen Plain

km² from 1980 to 2000, and then decreased by 142 km² from 2000 to 2015. Before 2000, the increase of the area of shallow waterlogging region and the decrease of the area of deep water body exerted much influence on the increase of saline land. After 2000, the area of the region covered by the water and the area of saline land both kept relatively stable.

5 Discussion

At different spatio-temporal scales, different factors had different influences on the occurrence and development of land salinization. Most studies focused on the influence from the shallow groundwater and the rise process of the soil salt. In natural process, shallow groundwater determined the salt aggregation of the land surface. While, when the hydrological process was interrupted by comprehensive human activities, the mechanism of salt aggregation changed into a complex pattern. Yang *et al.* (2010) depicted a mechanism through analyzing the transport process of soil water and salt, thus, in Songnen Plain, human activities had changed the surface hydrological process, and significantly decreased the ponding chances and occurrence frequency of rainwater and runoff. The ponding rainwater drove the salt accumulated in the upper soil from the depression to the hilltop, and formed the new distribution pattern of salt-affected soils. The shallow groundwater was not a main cause of the ongoing secondary soil salinization, although it played a significant role at early stages in the primary soil salinization. Liu *et al.* (2005) indicated that the hydrological change induced from the land use change was the main driving factors. The relationship between the increased saline land area and the distance to the water body edge indicated that the increase of saline land came from the dynamic of water body.

In this study, the area of saline land increased constantly from 1980 to 2000, and kept stable after 2000. The transformation among land covers showed that cropland, grassland, and water body had close transformation relationship with saline land. Moreover, there was also close transformation relationship among cropland, grassland, and water body, especially before 2000. Increase of paddy field, dry land, middle coverage grassland, low coverage grassland, and the nearly dry land surface including flood plain and swampland provided a large amount of interface for evaporation, which could carry soil salt to the ground surface. The area of the region where groundwater depth was larger than 3.3 m increased from 1980 to 2000, while, the area occupied almost the whole region after 2000. From 1980 to 2000, shallow groundwater could lead to land salinization, but was not the most important reason for the increase of saline land. Because the area of saline land increased when the area of the region where groundwater depth was larger than 3.3 m increased. Change of cropland, grassland, and water body induced from human activities and decrease of runoff and increase of irrigation and water transfer from outer basin were the main reasons for the increase of saline land from 1980 to 2000. After 2000, groundwater with relatively large depth could not exert much influence on land salinization. Protection of grassland and wetland prevented the increase of the area of saline land.

6 Conclusions

Land salinization was a severe and typical problem at the typical part of Songnen Plain. Land cover database and hydrological data were collected for analysis of spatio-temporal

change of saline land and hydrological process and causes of land salinization were determined from the transformation of saline land with other kinds of land covers and the change of hydrological processes. Conclusions had been gotten as follows:

1) The area of saline land increased from 4627 km² in 1980 to 5416 km² in 2000, and then decreased to 5198 km² in 2015. Saline land almost distributed in the whole region, except the northwest part of the study area. The transformation between saline land and other kinds of land covers mainly before 2000, and transformation among saline land, cropland, grassland, and water body were the major transfer types.

2) From 1979 to 2007, groundwater depth of the 16 wells was mainly larger than 3.3 m and had an increasing trend. Seasonally, the groundwater rose in spring, dropped down in summer with fluctuation, and rose again in autumn and winter. Spatially, the area of the region where the groundwater depth was larger than 3.3 m increased from 1980 to 2000, while the region almost occupied the whole region after 2000. Precipitation and evaporation changed little, while runoff decreased very much.

3) Groundwater could exert influence on land salinization before 2000. The nearly dried-up runoff, increase of paddy field (198.2%) and flood plain (67.6%), and decrease of high coverage grassland (52.3%), middle coverage grassland (36.8%), and lake (36.9%) increased the area of interface of vertical water movement, which increased the area of saline land indirectly. Change of cropland, grassland, and water body induced from human activities and the decrease of runoff and the increase of irrigation and water transfer from outer basin were the main reasons for the increase of saline land from 1980 to 2000. After 2000, groundwater with relatively large depth could not exert much influence on land salinization directly. Protection of grassland and wetland prevented the increase of the area of saline land.

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