SALINIZED WASTELAND EXPANSION IN WESTERN NORTHEAST CHINA DURING 1975-2004

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ABSTRACT

Due to human impact under climatic variations, western part of Northeast China has suffered substantial land degradation during past decades. This paper presents an integrated study of expansion process of salinized wasteland in Da'an County, a typical salt-affected area in Northeast China, by using Geographic Information Systems (GIS) and remote sensing. The study explores the temporal and spatial characteristics of salinized wasteland expansion from 1975 to 2004, and land use/cover changes during this period. During the past 30 years, the salinized wasteland in study area have increased by 11175 ha, and in 2004 covers 32.31% of the total area, in the meantime grassland has decreased by 32534 ha and in 2004 covers only 13.15% of the study area. Grasslands, croplands and swamplands were found the three main land use types converted into salinized wasteland. The major factors influencing salinized wasteland expansion and land use/cover changes were also explored. In general, climatic factors supplied a potential environment for soil salinization. Human-related factors, such as policy, population, overgrazing, and intensified and unreasonable utilization of land and water resources are the main causes of salinized wasteland expansion.

Key words: Salinized wasteland expansion, Land use change, GIS, Remote sensing, Da'an County, Northeast China

1. INTRODUCTION

Salinization and alkalinization are the most common land degradation processes, particularly occurring in arid and semi-arid regions, where precipitation is too low to maintain a regular percolation of rainwater through the soil (Farifteh et al., 2005). Nowadays soil salinization is an increasing environmental problem throughout the world. The global extent of primary salt-affected soils due to natural factors is about 955 M ha, i.e. approximately 7% of the earth's continental extent, while secondary salinization as a consequence of human activities affects some 77 M ha (Metternicht and Zinck, 2003). Salt excess in soils has detrimental effect on crop yields and agricultural production due to poor land and water management, and results in substantial losses of arable soils, especially in the arid and semi-arid areas (Cayuela et al., 2001). Furthermore, salinity also affects other major soil degradation phenomena such as soil dispersion, increased soil erosion, and engineering problems (Metternicht and Zinck, 2003).

The globalization as well as changing environment in China is affecting land-use change.

Coordinating the conflict between environmental conservation and land demands for food will continue to be a primary challenge for China in the future (Liu et al., 2005a). Soil salinization is one of the China's rural resource concerns (Rozelle et al., 1997), reduce crop yields and grassland productivity and leads to desertification. In western part of Northeast China, one of the main agricultural regions of the nation, soil salinization has been a environmental problem (Liu et al., 2002). Therefore, timely detection of Salinization/alkalinization, assessment of its degree of severity and the extent is vital.

For the researches on salinized land in western part of Northeast China, many efforts have been made to analyze current status of soil salinization, climate changes, landscape changes, influences of natural and anthropogenic factors (Pang et al., 2001; Huang and Meng, 1996; Li et al., 1998; Liu, 2001; Qiu, 2001). Yet quantitative knowledge on changes in land use at county level for long period is very little ((Pan et al., 2003), and there are no sufficient data at the landscape or regional scale to fully evaluate this problem. The objectives of this study were: (1) to assess the spatial and temporal characteristics of salina in Da'an County, a typical salt-affected area in western part of Northeast China, integrating maps and remote sensing images for a long period; (2) to demonstrate the effectiveness of combining remote sensing data in assessing salinization; and (3) to analyze possible factors influencing soil salinization and to provide useful information for improving grassland and cropland management practices and restoring the vegetation in this region.

2. MATERIALS AND METHODS

2.1. Description of the Study area

As a typical area affected by salinization in Northeast China, Da'an County (123°09′E - 124°22′E, 44°56′N to 45°46′N) is located in the northwestern part of Jilin Province, Northeast China, with an area of 4, 958 km^2. Its elevation is between 110 and 140m. The study area is characterized by a temperate, semi-arid continental monsoon climate. Seasons alternate between dry and windy springs, humid and warm summers with intensive rainfall, windy and dry autumns and long, cold dry winters. The mean annual temperature is 4.4 ℃ (1961-1990), with average maximum of 23.4℃ in July and average minimum –18.1 ℃ in January. The mean annual precipitation is 410 mm and evaporation is 1600 mm. Precipitation varies greatly within and between years. Seventy to eighty percent of total precipitation occurs between the middle of June and mid-August. The frost-free period of the study area is 137 d.

2.2. Datasets

2.2.1. Maps processing

To understand how land use/over change affects and interacts with global earth systems, information is needed on what changes occur, where and when they occur, the rates at which they occur, and the social and physical forces that drive those changes (Lambin et al., 1999). Despite ongoing research efforts on land-cover and land-use patterns, there remains a need for development of basic land-cover datasets providing quantitative, spatial land-cover information (Xavier and Szejwach, 1998).

The ARC/INFO (ESRI, 1994) GIS (Geographic Information Systems) software was used for the analysis of land use area change and the transition matrix analysis between land use types. In our study, multi-annual socio-economic statistical data, Landsat MSS images and Landsat TM images were collected for evaluating the temporal and spatial characteristics of salinized wasteland expansion and the land use change between 1976 and 2004. Projection system of conical equal area projection doubled standard latitude (Albers) and Beijing 1954 coordinate system is selected to integrate different phase data to realize the analysis of land use data.

2.2.2. Satellite image processing and land use classification

Landsat images were used for analyzing land use change between 1975 and 2004. The images recorded in August 1975 (MSS data), June 1986 (TM data), August 1996 (TM data), and June 2004 (TM data), were selected, because land use types are easy to identify in this period when plant grows exuberantly in Northeast China. All selected images are cloud free.

The Landsat images were enhanced using the linear contrast stretching and histogram equalization to help identify ground control points in the rectification to common ALBERS coordinate system based on 1: 100 000 topographic maps of China. For each TM/MSS scene, there are at least 20 evenly distributed sites served as Ground Control Points (GCPs). Meanwhile, an efficient land cover classification system was designed and applied in the study. The land use/cover classification was conducted through visual interpretation to guarantee the consistency and accuracy of data processing. The reference data was collected from field survey or from existing land use map that have been field checked. Large-scale aerial photos were also employed as reference data in accuracy assessment when necessary. The results showed that the Kappa indices are in minimum precision 0.72 by examining the classified results of RS images in three periods.

A land use classification system was applied to Landsat image data, according to the classification put forward by Liu et al (2005b) and the Chinese national Technical Standard for Land-use Survey (Chinese National Agricultural Regionalization Committee, 1979). The classified classes in each image were grouped into seven land cover categories: croplands, woodlands, grasslands, water bodies, built-up areas including urban areas, swamplands, and salinized wasteland (i.e. salina). Croplands include paddy and dry farming land. Woodlands include forest, shrub and others (e.g., orchards). Grasslands include three density dependent types: dense, moderate and sparse grass. Water bodies include stream and rivers, lakes, reservoir and ponds, and bottomland. Built-up land includes urban area, rural settlements and others such as roads. Swamplands include lands with a permanent mixture of water and herbaceous vegetation that cover extensive areas. Salinized wasteland are lands with salina accumulation and sparse vegetation, with vegetation cover less than 5%, they represent the severely salinized areas in this paper.

2.3. Spatial analysis

In determining land use change, a cross-tabulation detection method was adopted. A change matrix was produced. Then quantitative data of the overall land use changes and gains

and losses in each category can be compiled. The change matrix gives the knowledge of the main types of changes (directions) in the study area (Weng, 2002; Jia et al., 2004).

3. RESULTS AND DISCUSSION

3.1. Expansion of Salinized wasteland over the past 50 years

3.1.1. Temporal properties of salinized wasteland in Da'an County

The temporal change of salinized wasteland in Da'an County was illustrated in Figure 1.

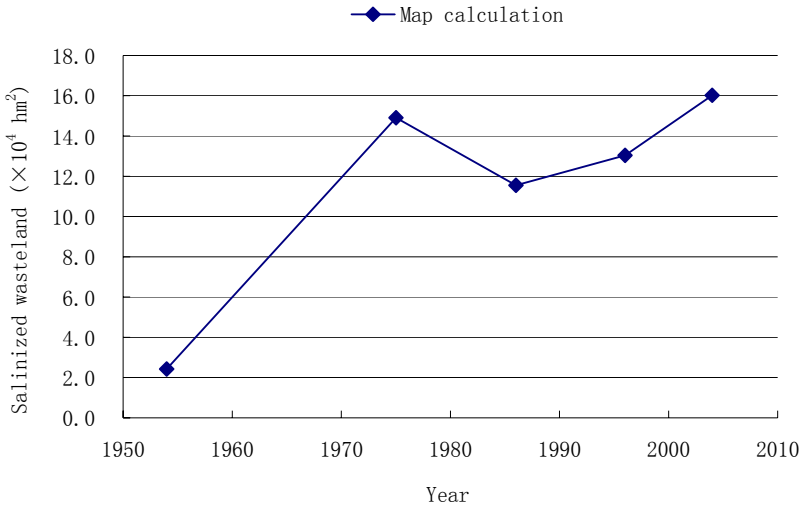


Figure 1.The temporal changes of salinized wasteland in Da'an County, Northeast China.

The salina area of Da'an County expanded from 14.90×10^4 ha in 1975 to 16.02×10^4 ha in 2004. Over the past decades, the process of expansion of salinized wasteland of the county experienced some up – down –up stages (Figure 3). During the stage of 1975-1986, the total area of salinized wasteland decreased by 22.5%, to 11.55×10^4 ha. The decrease rate was 2.0% per year. In this stage, relatively rich precipitation made some former salinized wasteland turned into swampland and brought a reduced area of salinized land.

Unfortunately, after the former abatement period, from 1987 to 1996, the precipitation showed a falling trend. Especially in 1995, Da'an County suffered great droughts during spring and summer. In addition, the excessive grazing of grassland accounted for the growth of salinized wasteland, which was related to the rapid population growth and the improved living standard since "the open-up to the outside world and the reform policy" were adopted in China. The salinized wasteland increased by 12.8% to 13.0×10^4 ha, with an annual rate of 1.3%. However, this size was still less than that in 1975 (14.9×10^4 ha). The salinized wasteland experienced another fast increase with an annual rate of 2.6% to 16.0×10^4 ha from 1996 to 2004. This increase resulted from climatic factors and anthropogenic disturbance in central part and in northern part, although the continuous heavy rainfall in 1998 somewhat lessened the salinization.

3.2. Transformation between salinized wasteland and other land use types

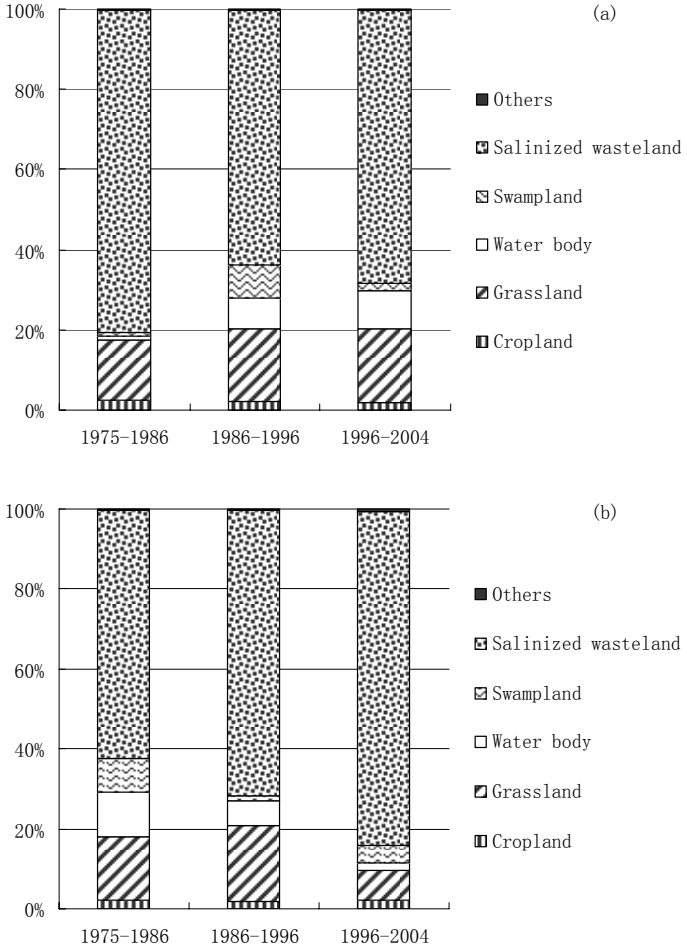


Figure 2. Area contribution of conversion between salinized wasteland and other land use types in Da'an County during four periods. (a) indicates the area contribution of land use types which were converted into salinized wasteland, and (b) indicates the area contribution of land use types which were converted from salinized wasteland.

Figure 2 demonstrated the conversion between salinized wasteland and other land use types in different periods. As shown in Figure 2 (a), increased salinized wasteland mainly originated from grassland, swampland, cropland and water bodies. Among these three land use types, grassland ranked the first. The percentage was 15.31%, 18.16% and 18.28% in different period, respectively. Proportion of salinized wasteland originated from swampland got one higher points during 1986-1996 (8.36%). This was partly attributed to drying out of swampland due to less precipitation in these two periods. The contribution of salinized wasteland originated from water body (mainly small lakes) was 7.62% and 9.72% in 1986-1996 and 1996-2004 periods, respectively, which is attributed to relatively less rainfall during these two stages.

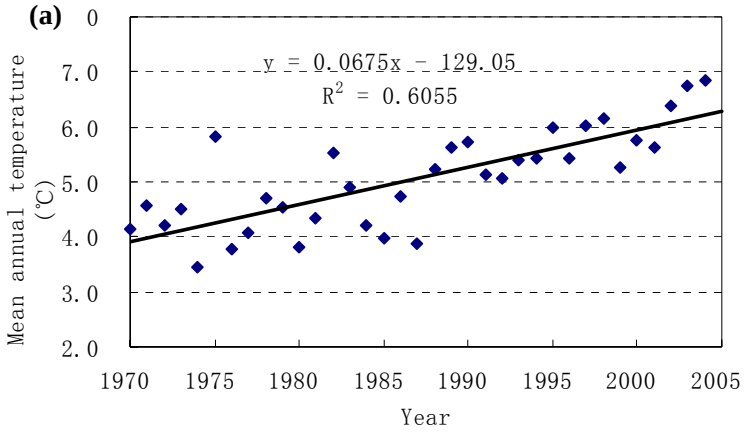
During the period 1975-2004, salinized wasteland was also converted into other land use types, such as grassland, water body and swampland. The percentage of salinized wasteland converted into water body was 11.23% and 6.33%, respectively, during 1975-1986 and 1986-1996.

3.3. Driving factors of expansion of salinized wasteland

Influenced by the climate and topography characteristics, there are two reasons for salinized land to form in this area. The first one is the dry climate, with evaporation being almost four times annual rainfall, and high mineralization of underground water, creating circumstances suitable for salt accumulation as the soil salt capacity increases gradually. The second is the unreasonable reclamation from grassland to cropland and digging canals for irrigation, which cause the underground water level to rise, and make the soil become secondary salinization.

3.3.1. Reasons of natural factors

The unfavorable hydrological conditions and dry climate accelerate salinization. On the one hand, in the last five decades, the study area have suffered frequent droughts, which led to increasing salinization and severely affected the agricultural development. Drought not only directly reduces productivity of crop and steppe generally, but also brings about soil salinization and desertification, which further indirectly affect regional sustainable development (Pan et al., 2003). On the other hand, in the West and East Piedmont of the study area, the sediments is mainly gravel and the slope is relatively steeper; there is a higher infiltration rate and faster groundwater runoff therefore, the salts leached from the top soil layers by rainfall can be rapidly transported downward by groundwater runoff. When the middle low plain is reached, groundwater runoff slows and dissolved salts are retained by soil and accumulate to high concentrations. As a result, in the middle low plain, the conditions are worse: almost stagnant groundwater, runoff without discharge except for evaporation, a shallow water table and a higher degree of mineralization, all of which are favorable for salinization. Furthermore, the semi-arid climate, characterized by low precipitation and very high evaporation, combined with unfavorable hydrological condition, increases land salinization.



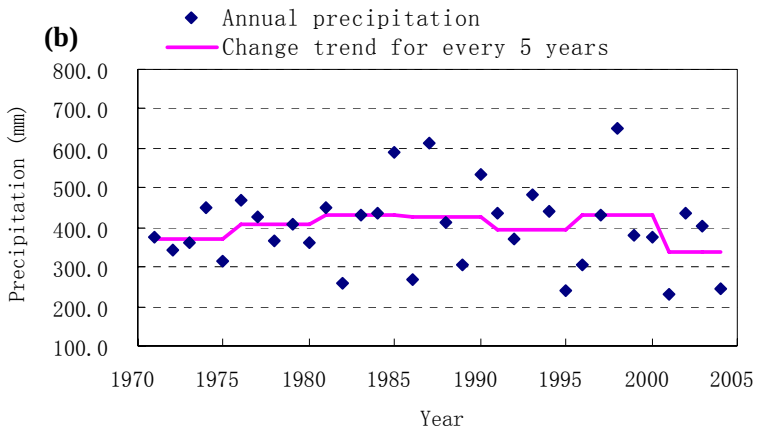


Figure 3.Changes of mean annual temperature (a) and annual precipitation (b) during 1975-2004 in Da'an County, China.

In the study area, the gradually increased air temperature led to intensive evaporation, which resulted in salinity accumulation in soil surface when precipitation was much less than normal level. In the past three decades, droughts have frequently endangered the Da'an County, thereby increased area of salinized wasteland and severely restricted sustainable development. Climate played an important role in the landscape changes.

The precipitation fluctuated in the past 30 years. To further analyze the effects of precipitation fluctuation on size of salinized wasteland, we compared the salina size obtained from maps with precipitation in that year. In 1975, the precipitation is very low (314.5 mm, 76.7% of mean annual precipitation, 410 mm). Consequently, the evaporation increased and salinity congregated on the surface with moisture, which resulted in severe salinization or aggravation of the salinizeded land, especially for swamplands in the southern part of the county. It was the reason that can't be ignored accounting for the sharp increase of salinized land in 1975 (Fig. 2) of the study area.

During the period of 1976-1986, the precipitation is relatively high compared with that in former period, some salinized land turned back into swmaplands. As a result, the increasing area of salinized land reduced and water area and swamaplands increased a little. In 1995, Da'an County suffered great spring and summer droughts, with only 60 mm of precipitation in 200 days, which not only directly reduced water area and wetlands but also caused serious damage to grassland and exacerbated land salinization. From 1996 to 2004, the precipitation changed as the trend of low-high-low. Flood in 1998 due to large continuous rainfall created some new swamplands and the following lower precipitation and more drought climate made some of the wetlands disappear, which is the major process accounting for the landscape changes in this period.

3.3.2. Socio-economic factors

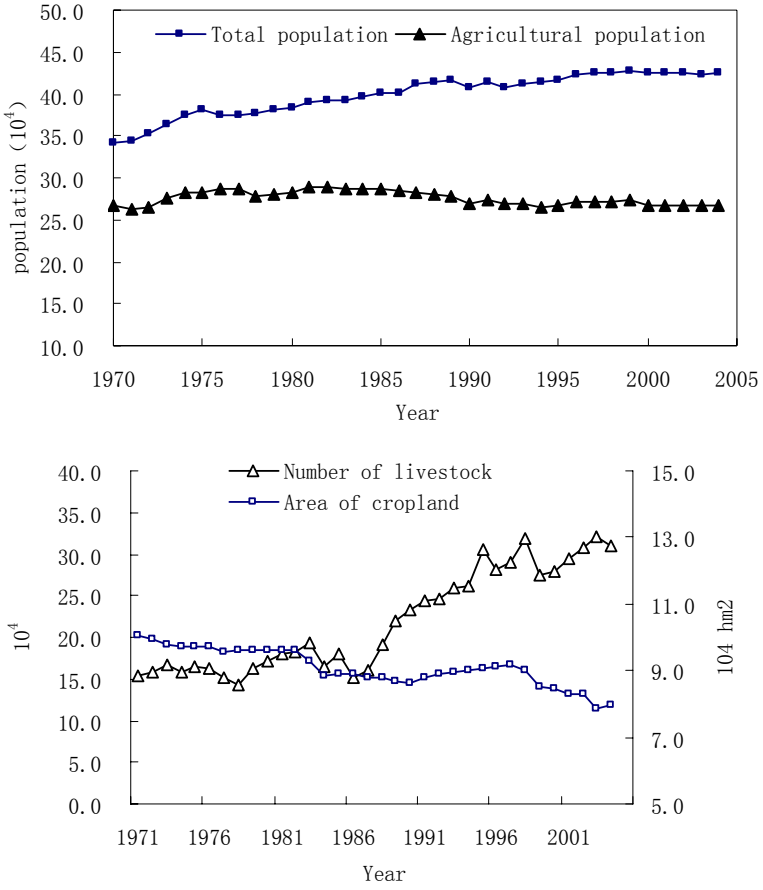


Figure 4. Changes of total population, agricultural population, cropland and number of livestock in Da'an County, China.

In this study, due to the increase in population and the concomitant requirement of grain after the founding of the People's Republic of China in 1949, the reclamation of farmland increased, which accelerated the cultivation of grassland and swampland. As shown in figure 4, total population of the study area increased by 23.2%, from 345 038 persons in 1971 to 425 216 in 2004. Agricultural population increased by 10.73%, to 266 830 persons in 2004. The rapid population growth brought a heavy burden to croplands and grasslands.

In Da'an County, agricultural and economic policies partly affected land use changes. At the end of the 1978, in order to encourage farmers, the Chinese government reformed the land tenure policy and introduced a system of household contract responsibility, in which remuneration was linked to output. In Da'an County, newly cultivated farmland increased from 1980, though was limited by the geographic situation, the percentage of total area is not so large. Owing to salinization, some of farmland had to be abandoned after reclaimed for a period, but the area of newly reclaimed farmland is less than that of abandoned cropland.

On the other hand, the unreasonable development of stockbreeding reduced the ground cover, thereby increasing the evaporation, soil temperature and soil organic decomposition. The $NaHCO_3$ and Na_2CO_3 produced after decomposition of soil organic matter are highly soluble in soil liquid at higher soil temperatures. In the past 30 years, the livestock increased greatly, from 154426 to 309456 capita (Figure 4). The excessive and unreasonable use of

grassland destroyed the structure of original landscape. The area of salt-affected patch in grassland expanded, which generated a vicious circle and the depressed productivity of grassland continuously.

4. CONCLUSIONS

During the period 1975 – 2004, soil salinization expansion took place in Da'an County, Northeast China. Salinized wasteland increased by 562% in the three decades. Net increase of salinized wasteland was 135995 ha, concomitant with substantial decrease in grassland of 104697 ha. These changes bore an interactive relationship with the environment, especially increased air temperature and variable precipitation. Climate warming created a potential environment for soil saliniztion. Apart from natural factors, land use policy, economic systems and population growth were also main driving forces that jointly determined how local dwellers changed the landscape pattern. The results drawn from our study are important for scientists as well as policy makers for assessing a number of cutting-edge issues associated with global change and sustainability.

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