Is Desertification Reversion Sustainable in Northern China? – A Case Study in Naiman County, Part of a Typical Agro-pastoral Transitional Zone in Inner-Mongolia, China

Xueyong ZHAO, Yayong LUO, Shaokun WANG, Wenda HUANG and Jie LIAN

Naiman Desertification Research Station
Cold and Arid Regions Environmental and Engineering Research Institute
Chinese Academy of Sciences
320 Donggang West Road, Lanzhou 730000, China
e-mail: nmzhaoy@yahoo.com.cn

Abstract

Analyses of data on the desertified land area, cropland area, Xihu Lake water table and annual precipitation of Naiman County showed that the total area of desertified land had decreased from 4198.07 km² in 1975 to 3297.3 km² in 2005. Irrigated cropland steadily increased from 115.74 km² in 1959 to 368.79 km² in 2005 while rain-fed cropland decreased from a maximum of 1251.86 km² in 1961 to 568.33 km² in 2005. The annual precipitation fluctuated dramatically and there were two drought periods of ten years in the period from 1961 to 2005. The water table of Xihu Lake decreased consistently. The relationship between annual precipitation and water tables is not significant, but that between irrigated cropland and water tables is. This tentatively shows that water resource reduction, to a large extent, is due to overuse of water for irrigation.

Considering the expansion of irrigated cropland and reduction of annual precipitation and water tables, there is no doubt that desertification reversion will not be sustainable in Naiman County if alternative land use strategies are not available and water is not used more efficiently.

Key words: land use, Naiman County, sustainable desertification reversion, water resource

1. Introduction

Desertification is a process of land degradation in arid, semi-arid and sub-humid areas due to adverse climate and human activities (Middleton, 1997). Due to limited precipitation and intensified land use, desertification is expanding at an ever-increasing averaged annual rate in northern China: from about 1560 km² in the 1950s and 1960s, to about 2100 km² in the 1980s (Zhu, 1994) and 2,460 km² in the 1990s (Wang, 1999). As a result, the total area of desertified land reached about $3.34 \times 10^3$ km² in 2000, with 851 counties suffering from desertification (Wang, 2005).

In the late 1930s, farmers in the northwestern parts of Liaoning Province initiated efforts to control desertification to protect their land and livestock. In the later 1970s, the Chinese government initiated a well-known greening project, ‘The Sanbei Shelterbelt System,’ to restore desertified land and degraded ecosystems. ‘The Sanbei’ refers to the northwestern, northern and northeastern parts of China and stretches about 4,400 km from Xinjiang in the westernmost region to Heilongjiang in the northeasternmost region of China. After nearly half a century, great achievements have been made in combating desertification at some sites, such as in the agro-pastoral transitional zone in Inner-Mongolia. As a whole, however, desertification is still expanding and large areas of cropland and grassland have been engulfed by encroaching sand. In recent years, the impact of desertification has made a deep impression due to frequent sand and dust storms, which damage infrastructure, lives and living environments, not only in the places where the storms occur, but even in places far away.

Naiman County is located in the heartland of the Horqin Sandy Land, which is a section of the typical agro-pastoral transitional zone in eastern China. The total area of the county is 8,120 km² and it stretches about 140 km from south to north. It is characterized by hills in the south and sandy lands in the middle and north. It also belongs to the intermediate zone between semi-arid and semi-humid areas, with a monthly mean air temperature of 22°C in July and –16°C in January. The long-term annual mean precipitation is about 358 mm and the potential evaporation is 1,900 mm (Zhao, 1992).

The landscape of Naiman County was once grassland with scattered Ulmus pumila trees. Since the 1870s,
however, farmers from Liaoning and Shandong provinces have immigrated in masses into this area causing rapid increases in population and cropland and reduction of grasslands. As a result, desertification has intensified. Responding to the imminent threat of desertification and the central government’s initiation, Naiman County launched a long-term campaign to combat desertification in the late 1970s. After 30 years, desertification has been reversed at last, but there is less water available, with rivers characteristically drying up, lakes shrinking and underground water tables falling.

Subsequently, researchers have pointed out that this trend will definitely increase the fragility of the region’s ecosystems and compromise efforts to combat desertification.

Therefore, the question has been raised as to whether it is possible or not to achieve a sustainable desertification reversion, or how a sustainable desertification reversion may be achieved in the agro-pastoral transitional zone of northern China. With Naiman County as a case study, changes in desertified land, land use and, particularly, in irrigated cropland and annual precipitation are discussed in this article to examine the possibility of sustainable desertification reversion.

Sustainable desertification reversion in this article refers to desertification reversion either by natural processes after human disturbance has been excluded/moderated, or with human assistance that does not compromise the needs of natural or managed ecosystem succession and social development in the future.

2. Methods and Data Sources

Data on desertified land areas were obtained from the data bank of the Naiman Desertification Research Station, the Chinese Ecosystems Research Network and Wang Tao (2005). The water table of Xihu Lake (about 5 km northwest from Daqintala, the central town of Naiman County) has been measured by theodolite since 1995 at a fixed point (set as 0 m) on the east shore of the lake. Climate data are from the Naiman Meteorological Station and cropland data are from the Annual Statistic Book of Naiman County.

The relative variation (RV) of the annual precipitation was calculated as follows:

\[ RV = \frac{(P_i - P_a)}{P_a} \]

where \( P_i \) is the annual precipitation in year \( i \), and \( P_a \) is the averaged annual precipitation in the identified period. Here \( P_a \) denotes the annual mean precipitation in the period of 1961 to 2005.

Microsoft Excel 2003 and SPSS Version 11.0 were employed to present and analyze the above data.

3. Results

3.1 Changes in desertified land in Naiman County

Naiman County was once one of the most severely desertified counties in the agro-pastoral transitional zone of Northern China. From Fig. 1, it is clear that the total desertified land reached a peak of 4,198.07 km², about 51.7% of the total land of the county in 1975 and then decreased to 3,297.3 km² in 2005. The area of fixed dunes decreased in general from 1975 to 2005, although it showed a slight increase from 1995 to 2002. While the shifting dune area increased from 1975 to 1985 and then decreased steadily, the semi-shifting dune area was relatively stable from 1975 to 1995 and then decreased from 1995 to 2005.

These kinds of changes in desertified land present not only a complicated pattern of desertified land change, but also a complicated interaction of causes of desertification in this region. As a general trend, as of 2005, desertified land still occupied a large portion of the county, a little more than about 40.6% of the total land area.

The decrease in fixed dunes does not by itself indicate desertification, but quite possibly a transition from fixed dunes into cropland due to cultivation of inter-dune areas and relatively flat patches of fixed dunes. The latter is often observed in the areas surrounding the Naiman Desertification Research Station (Fig. 2).

![Fig. 1 Changes in desertified land in Naiman County, Inner-Mongolia.](image-url)
3.2 Land use change characterized by growing intensity and rapid expansion

Changes in land use are generally driven by growing population, new technology, pursuit of income and different land use policies (William, 1994). The temporal change in land use patterns in Naiman County from 1959 to 1961 was characterized by short-term increases in rain-fed cropland, which reached a peak of 1,251.86 km² in 1961. After that it decreased until the middle of the 1990s and then jumped again (Fig. 3).

Irrigated cropland increased steadily from 115.74 km² in 1959 to 368.79 km² in 2005, while rain-fed cropland fluctuated dramatically. It is interesting that there was a relatively stable phase of both rain-fed cropland and irrigated cropland in the period from 1975 to 1995. This is closely related to changes in land use policy in that...
period (Liu, 1993a).

The Chinese government carried out ‘land tenure reform’ in 1979 and implemented an initial ‘trial policy’ of shifting land tenure every three years. During this period, farmers worried about the frequent change in the tenure period, so most of them did not dare to expand their cropland or even increase their investment in the same land (Liu, 1993b).

In 1997, the government adopted a policy of ‘no change in land tenure for 30 years,’ and land was redistributed to individual farmers, so some farmers started to enlarge their irrigated cropland again. From Fig. 2, it is clear that irrigated cropland increased consistently while rain-fed cropland continued fluctuating after 1997. Changes in land use are also driven by farmers’ capacity and expectation for income growth (Sara, 2002). The impact of land use policies is more profound on land tenure in China.

3.3 Changes in water resources

Water resources are the primary limiting factor in the agro-pastoral transitional area. However, with water use growing due to the increase in cropland and civil utilization, the availability of water has decreased greatly since the end of the last century in this region.

Figure 4 shows the change in the water table of Xihu Lake, one of the three largest lakes in Naiman County. It is clear that the water table had consistently decreased since 1995 and dried up completely to a depth of –2.14 m in 2001 (Fig. 5).

After the lake dried up in 2001, the water table continued to decrease due to irrigation in the near vicinity, and the exposed lake bed was planted with _Tamarix chinensis_ bushes for the first three years to cover it, with the expectation of recovery of the water. Unfortunately, the bushes died off and the lake has still not been restored up to today. Finally, the exposed lake bed was cultivated into cropland and irrigated by pumping water from underground in 2004.

Irrigation is identified as the largest use of water in Naiman County, accounting for 70% ~ 75% of the total water use in this county. However, industrial consumption has been growing in recent years due to introduction of cement, pharmaceutical and chemical factories around the town of Daqintala. These factories are near to Xihu Lake, too. Unfortunately, there are no data on the volume of water consumed by these factories.

The introduction of several factors would not pose a threat to the water cycle in a humid area, but it is a totally different story in semi-arid and arid regions.

3.4 Changes in annual precipitation

Precipitation is the major source of water in Naiman County. However, the annual precipitation varies dramatically, both annually and seasonally.

It is obvious from Fig. 6 (left) that the maximum annual precipitation was 567.1 mm in 1986 and the minimum, 213 mm in 2000. Over a period of 45 years, the average annual precipitation was 357.33 mm, the number of years with annual precipitation of more than this value was 17 and less than this value, 28. This pattern indicates that the annual precipitation is drought-prone and that above-average precipitation falls mostly in high

![Fig. 5 Xihu Lake, one of the largest lakes in Horqin Sandy Land, dried up in May 2001. It covered an area of 26 km² and had an averaged volume of about 1.2*10⁸ m³ (photo by Xueyong Zhao, 2002)](image)

![Fig. 6 Changes in annual precipitation (left) and relative variation (right).](image)
intensity episodes. That is why this region often suffers from both droughts and floods.

Within the period from 1961 to 1975, the annual precipitation fluctuated moderately, but in the period from 1975 to 1995, the annual precipitation fluctuated rather dramatically. There was even a greater increase in 1998, and the general trend has been decreasing since then, and this long-lasting dry period continues today. This drought has caused large losses in crop production.

From Fig. 6 (right), it is clear that there was a drought period of ten years from 1965 to 1975 and a second drought period of ten years from 2000 to 2009, denoted by continued negative relative variation.

3.5 Relationship of the water table to irrigated cropland and annual precipitation

The reduction of water availability is a result of a complex process of nature-human interaction. Based on the data available, analysis of the relationship between the reduction of the water table and changes in irrigated cropland and annual precipitation shows that there is a significant correlation between the Xihu water table and irrigated cropland (Kendall’s τc: -.782, 2-tailed test); Spearman’s ρ: -.909, p < 0.01; 2-tailed test). The correlation between annual precipitation and the Xihu water table, on the other hand, is not significant. Of course, this does not definitely mean that there is no correlation between the annual precipitation and changes in the water table.

Related research reveals that there is a significant correlation between woodlands and total desertified land (Pearson: -.974, p < 0.01; 2-tailed test) as well as dunes and precipitation (Kendall’s τc: 0.600, p < 0.05; 1-tailed test) (Zhao, 2009).

Changes in land use impact the re-distribution of precipitation and underground water and further influence the restoration of vegetation and the stability of restored vegetation.

4. Discussions

4.1 Changing land use from simple spatial expansion to intensified management

As stated above, the original landscape of Naiman was a tree-scattered grassland. In the 1870s, the then authority of the Qing Dynasty changed its previous policy of “Prohibiting Cultivation of Grasslands in Mongolia” to “Encouraging Cultivation of Grasslands in Mongolia.” Farmers swarmed into this region and engaged in “slash and burn” cultivation initially. Cropland was all rain-fed and gradually spread from the southeastern part into the northwestern part where the land was less suitable for cropping. That is why rain-fed cropland was approaching its maximum of more than 1,200 km² in the early 1960s, covering about 15.4% of the total area of Naiman County. This simple rapid spatial expansion of rain-fed cropland led to severe desertification (Naiman Annals Committee, 2003). The high proportion of rain-fed cropland was also reflected in the farmers’ lower capacity for production. Increased intensification of land use is characterized by increased irrigation of cropland, introduction of species with high productivity and application of fertilizers. This intensification results in increased water use and ecosystem fragility (Zhao et al., 2009).

Introduction of maize and application of chemical fertilizers greatly increased cropland productivity and water consumption. In the period from 1949 to 1976, the average yield of maize on rain-fed cropland was low, about 1,500 to 2,500 kg ha⁻¹, but this figure increased to 9,500-12,500 kg ha⁻¹ by the middle of the 1980s, and 12,500-15,000 kg ha⁻¹ by 2000 (Zhao et al., 2009). Meanwhile, the water volume used for irrigation of maize increased from 1,080 ton ha⁻¹ y⁻¹ in 1949 (Naiman Statistic Bureau, 2005) to 3,240-4,725 ton ha⁻¹ y⁻¹ in 2005. This figure could be greatly reduced by coating the irrigation canals with concrete slabs 5 cm thick (Zhao et al., 2009).

The increase in irrigated cropland is closely related to advancements in technology, such as techniques for digging deep wells equipped with centrifugal pumps driven by either electric power or diesel engines, and particularly, changes in China’s land use policy (Sara et al., 2002). In recent years, farmers’ expectations for increasing their capital earnings have become an important driving force in land use intensification. Eighty-six percent of farmers have expressed their intention to enlarge their irrigated cropland and increase their land productivity, although increases in productivity are already limited to simple input of fertilizer and irrigation (Sara et al., 2002).

Irrigated cropland has increased land productivity and helped to reduce rain-fed cropland and restore degraded vegetation (Chang, 2001), but the growth of irrigated cropland has had a severe impact on water resources, ultimately leading to the drying up of lakes and rivers and reduction of the underground water table. Cases are often reported in other parts of the agro-pastoral transitional zone, as well, in which water resources have been diminished due to irrigation (Liu, 2001).

Intensification of land use in Naiman County has manifested with the invasion of irrigated cropland into...
riverbeds too. There are two larger river systems across Naiman County. One, the Jaolai River, dried up in 1999 and the other, the Laoha River, dried up in 2009 (Fig. 7). With a reduction in runoff, a large area of riverbed was exposed to the air and farmers cropped this land with rice initially, and then maize. This kind of land use has not only changed the courses of rivers and consumed large amounts of water, but also had a profound impact on the hydrological process of the river systems (Zhao et al., 2009).

4.2 Tenuous desertification reversion

Generally speaking, desertification has been reversed in Naiman County, although the shifting dune area increased from 1975 to 1985 and 2002 to 2005 (Fig. 1). Shifting dunes are popularly identified as the first target to be fixed. Fluctuation of the shifting dune area indicates stochastic interference of driving forces, such as over-grazing or over-cultivation. Changes in shifting dunes are closely related to changes in annual precipitation (Zhao et al., 2009). Stochastic interference of driving forces cannot lead to stable restoration of the ecosystem.

As of 2005, desertified land still occupied a large proportion of the total land, about 40.6% of the total land. Unplanned expansion of irrigated cropland is compromising the basis for sustainable desertification reversion and conservation of water resources. Water resource reduction has been reported nationwide, e.g., the disappearance of Lap Nor in Xingjiang in the 1970s and the drying up of Juyan Lake in the 1980s, the largest lake in western Inner-Mongolia (Zhao, 2000; Zhang, 2001). Causes of the drying up of lakes are said to include over-use of water resources in the upper reaches of rivers above the lakes or around the lakes (Qin, 2001; Ding, 2006).

As expected, desertification reversion should be a process of profound improvement of the whole ecosystem. That is to say that desertification reversion should lead to the improvement of all aspects of the degraded ecosystems, and not to undermine the capacity of water resources to sustain consistent desertification reversion. Therefore, it is recognized that there must be some problems in the current desertification reversion practices and assessment systems. In practice, combating desertification should comprise a systematic task to promote both desertification reversion and environmental health at the same time. The current indices of desertification assessment only include vegetation coverage, the ratio of shifting sand area to the total monitored area, and bio-productivity (Zhu, 1994; Wu, 2002). There is no consideration of changes in the most limiting factor: water resources.

Researchers (Zhao et al., 2009) have found that the productivity of restored grasslands is decreasing. Therefore, with a growing population and climate change, it is necessary to develop a series of indicators, including vegetation composition, productivity, soil properties and water availability to make accurate, fact-reflected assessments of desertification reversion.

4.3 Impacts of land use changes on water resources challenge the reversion of desertification in the agro-pastoral zone

Expansion of irrigated cropland is the primary cause of the reduction in water resources. Of course, it is not to say that there is no correlation between annual precipitation and water resources; however, that is not significant. A close relationship between irrigated cropland and water resources has also been reported by other researchers (Yu, 2004).

Desertification is also significantly related to other land uses, such as woodlands and grasslands. The significant negative correlation between woodlands and total desertified land reveals that establishment of vegetation consisting of trees and bushes is an important measure in combating desertification, although the ecological significance of tree species with great water consumption has been questioned and even doubted (Zhang, 2003).

Research also reveals that there is a significant correlation between shifting dune areas and precipitation (Zhao et al., 2009). This shows that climate change still plays an important role in desertification dynamics. Revegetation has normally been carried out in semi-fixed and fixed areas rather than in shifting dune areas, in which it is relatively difficult for seed reserves to germinate due to strong winds and lower moisture in the top soil (Zhao, et al., 1999; Xu, 1993). Revegetation of shifting dunes, mostly a natural process in Naiman County, is mainly dependent on precipitation, particularly precipitation in the spring (Zhao, et al., 1999).

In recent years, China launched a campaign against desertification known as “Green for Grain” or “Reversion of Over-cultivated Cropland into Grassland.” This campaign has reaped immediate positive effects, but the question remains of how to maintain a proper amount of cropland to feed the growing population. Another campaign has been “Exclusion of Grazing.” This campaign has also been successful where restoration of degraded grassland was given priority (Peng, 2004). However, exclusion means “reducing the food of livestock,” so livestock raisers have had to find alternative sources of food for their livestock or alternative means of living for themselves. That is why these ecologically feasible campaigns have been challenged for economical unfeasibility. These two campaigns have promoted natural restoration of degraded ecosystems and are water-saving measures, but their drawback is how to meet the needs of both humans and livestock.

Therefore, it is clear that desertification reversion in Naiman County, to a large extent, has been sustained mainly by increased irrigated cropland and reduced rain-fed cropland with reduced land use pressure, such as exclusion of livestock from grasslands and “Reversion of Over-cultivated Cropland into Grassland.” However, increased irrigated cropland uses too much water and leads to severe water scarcity and increased fragility of all ecosystems, and the two campaigns underway have the drawback of not meeting needs for development.
Therefore, desertification reversion is, in a sense, sustainable neither in Naiman County nor the whole agro-pastoral transitional zone in China. Achieving sustainable desertification reversion will require the systematically pooled wisdom of farmers’ land use capacity, researchers’ innovative scientific findings and government’s science-based decisions.

5. Conclusion

Based on the above analyses, we tentatively conclude that:

Desertification in Naiman County has been reversed and the proportion of desertified land to the total has decreased from 51.7% of the total land of Naiman County in 1975 to 40.6% in 2005. The rapid decrease in rain-fed cropland has been helpful to desertification reversion. The margin between people’s needs and reduced rain-fed cropland has been bridged by the increase in irrigated cropland, but the increase in irrigated cropland has led to a reduction of water resources. There is a significant correlation between irrigated cropland and changes in the water table of Xihu Lake.

The annual precipitation in Naiman County has changed dramatically. There is no significant correlation between the annual precipitation and the water table, but this does not definitely mean there is no relation between annual precipitation and changes in the water table.

Due to over-expansion of irrigated cropland, dramatic changes in precipitation (mostly toward being drier) and reduced water resources, there is no substantial evidence to show that desertification reversion in Naiman County is sustainable if alternative land use strategies are not available.

Acknowledgments

This article was funded by research projects—2009CB421303 and KZCX2-YW-431. We are also grateful for the help of our colleagues at the Naiman Desertification Research Station, the Chinese Ecosystems Research Network. Gratitude also goes to Professor Chang Xueli for his help in satellite image interpretation.

References

Xueyong ZHAO

Born in Inner-Mongolia in 1963, Ph.D and research professor and head of the Naiman Desertification Research Station (NDRS), the Cold and Arid Regions Environment and Engineering Research Institute (CAREERI), the Chinese Academy of Sciences, has been mainly engaged in dryland ecosystem research, specifically in combating desertification and sand and dust storm monitoring since 1988 in Horqin Sandy Land of eastern Inner-Mongolia and has published more than 100 research articles and three monographs. He is also one of the holders of UN prize for “Success in saving the dry-lands” and deputy editor of the Journal of Desert Research.

Yayong LUO

Born in Gansu Province in 1983, Ph.D and research assistant of CAREERI, mainly engages in plant eco-physiology, specifically in water use efficiency and nitrogen dynamics of plants in Horqin Sandy Land and published 12 research articles. E-mail: Louyy816@126.com

Shaokun WANG

Born in Shanxi Province in 1982, Ph. D candidate of CAREERI, mainly engages in soil microbial dynamics and functions in litter decomposition in the ecosystems of desertified land and published six research articles. E-mail: kkunny@163.com

Wenda HUANG

Born in Gansu Province in 1980, Ph. D candidate of CAREERI, mainly engages in molecular biological responses of plants to the change of habitat gradients of desertification in Horqin Sandy Land. E-mail: huangwd04@lzu.cn

Jie LIAN

Born in Gansu Province in 1985, Ph. D candidate of CAREERI, mainly engages in the research of changes of water bodies in relation to land use change based on interpretation of satellite images. E-mail: ape-manzy@qq.com

(Received 10 April 2010, Accepted 3 June 2010)