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Aeolian desertification and its control in Northern China

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Abstract

Aeolian desertification is a kind of land degradation through wind erosion resulted from the excessive human activities in arid, semiarid and part of sub-humid regions in Northern China. To compare the results of remote sensing data in the late 1950s, 1975, 1987, 2000 and 2010, we can summarize that the expansion of aeolian desertified land in Northern China has been accelerated for 5 decades, as its annual expanded rate was 1,560 km^2 during the late 1950s and 1975, 2,100 km^2 between 1975 and 1988, 3,600 km^2 from 1988 to 2000, and -1,375 km^2 from 2000 to 2010. The desertified land kept expanding before 2000 and began to get rehabilitated since 2000. The impact of human activity on the aeolian desertification process is much more active than that from natural process which mainly incarnates on land use change (from rangeland to farmland) and increased land use intensity (over-cultivation, over-grassing, and over-fuelwood collection). The natural vegetation cover destroyed by the human activities has accelerated the development of aeolian desertification. China has made great progresses in understanding and combating aeolian desertification through decades of effort and there were many projects carried out for the prevention and control purpose. The National Project of Grain for Green Program is the most important one with 1060 counties of 22 provinces involved. The objective is to withdraw 3.67 million ha of dry land farming and degraded steppe, and 5.13 million ha of aeolian desertified land suited to reforestation and re-vegetation will be rehabilitated. There are about 8 million ha of lands suffering from aeolian desertification will be brought under control in the next ten years and 26.67 million ha of windbreaks will be planted. The total investment from the central government is estimated to be 75 billion RMB (11 billion USD).

Key Words: Aeolian desertification, Development process, Combating, Northern China

1 Introduction

According to the United Nations Convention to Combat Desertification (UNCCD, 1994), desertification is a very serious environmental and socio-economic problem facing the world. There are several major types of desertification including aeolian desertification, soil and water erosion, and salinization. Aeolian desertification is one of the major desertification types found in Northern China (Wang, 2004).

Aeolian desertification has been caused by the conflict between environment/resources and development, which results in the destruction of resource-environment systems and poverty, and also endangers the social stability and sustainable development of economic systems. It has attracted wide attention in international communities. China is suffering from severe desertification, and the rapid development of aeolian desertification in Northern China and its tremendous environmental and social consequences have attracted considerable attention. Aeolian desertified lands in China are mainly distributed in the arid, semiarid, and in part of the sub-humid regions of Northern China, including Inner Mongolia, Ningxia, Gansu, Xinjiang, Qinghai, Tibet, Shaanxi, Shanxi, Hebei, Jilin, Liaoning and Heilongjiang provinces (Wang, 2011). Based on 30 years of study, we defined aeolian desertification as a land degradation characterized by wind erosion mainly resulting from excessive human activities in arid, semiarid, and sub-humid regions (Wang, 2008).

China in the last 60 years has put great effort into comprehensive research to control aeolian desertification.

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Researchers have made much progress and as a result, much work to control desertification has been conducted in regions with fragile eco-environmental conditions and frequent human activity. Through remote sensing monitoring and field investigations in large regions, we have achieved a preliminary understanding of the aeolian desertification processes concerning the causes, distribution, types, and damages in Northern China. Through multidisciplinary research of aeolian desertification processes, including blown sand dynamic processes, biological processes and anthropogenic processes, the roles of human and natural impacts have been established and a multi-level comprehensive indicator system of aeolian desertification with blown sand activity has been put forward (Wang et al., 1999).

2 Development of aeolian desertification in last 60 years in Northern China

From 1950 to 2100, aeolian desertification has mainly developed in the agro-pastoral zones of Northern China, marginal lands on the outskirts of deserts, and low reaches of inland river basins in Western China. The total aeolian desertified land in China was 0.137 million km^2 in 1955, increased to 0.176 million km^2 in 1975, 0.334 million km^2 in 1987, 0.386 million km^2 in 2000, and 0.376 million km^2 in 2010 (Fig. 1). During the last 60 years, aeolian desertified land expanded with an increased annual rate until it began to decrease in the early 2000s (1,560 km^2 from the late of 1950s to the mid-1970s, 2,100 km^2 from the mid-1970s to the late 1980s, 3,600 km^2 during the 1990s and -1,375 km^2 from 2000 to 2010). The aeolian desertified lands lost huge amounts of soil which was carried to Eastern China by dust storms, depositing in Beijing, and even in Korea and Japan. The direct and indirect economic loss caused by the aeolian desertification is estimated to be approximately 45 billion RMB (5.6 billion USD) per year and threatens the nearly 300 million residents of Northern China.

Aeolian desertified lands in China, in 2010, cover a total area of 37.59×10^4 km^2 and appears to be a discontinuous arcuate-belt from Northeast China to North China and Northwest China. Of this total area, 29% is distributed in the mixed farming-grazing regions, rainfed farming regions in the eastern part of semiarid zone, and part of sub-humid zone (mainly in the Otindag Sandy Land, Horqin Sandy Land, Bashang area of Hebei Province and Houshan area in Inner Mongolia) with wind erosion and sand sheet as the striking features. There is 44% of the aeolian desertified land in the middle and western parts of the semiarid zone and desert steppe zone (mainly in the middle of Inner Mongolia) with reactivated fixed dunes and shifting sand spread; The remainder of the aeolian desertified land (27% of the aeolian desertified area) is distributed at the margin of oases in the arid zone and lower reaches of inland rivers (mainly in the Alxa area of west Inner Mongolia, northern part of the Hexi Corridor area in Gansu and the lower reaches of the Tarim River in Xinjiang). Fixed dunes are the main feature of this area.

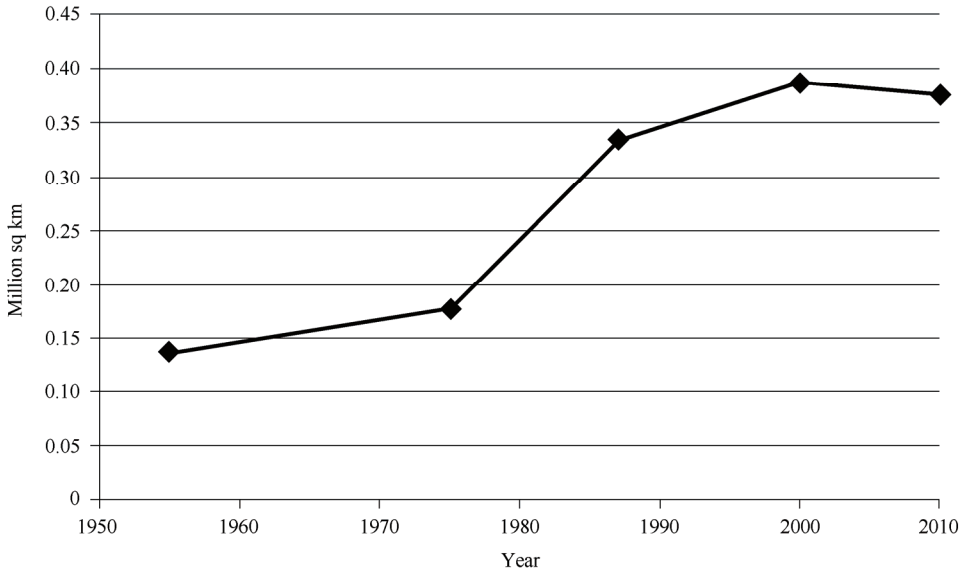

Fig. 1 Aeolian desertification in China, 1955–2010

3 Causes of aeolian desertification in Northern China

The cause of aeolian desertification is a basic subject in aeolian desertification research. It is the foundation to make effective control measures that will solve the degradation problem. In fact, we can divide the cause of aeolian desertification into two categories: natural cause and human cause.

Natural occurrence and development of aeolian desertification is a common phenomenon in arid and semiarid regions, especially in China. For example, wind erosion and moving dunes encroach on oases, river terraces, and cause natural vegetation destruction in the wind gap area. Natural causes are: (1) global climate change, especially global warming and aridification in the mid-latitude regions – a major ecologically favorable condition for the development of desertification, and (2) a dry climate, with erratic precipitation, an aeolian soil texture and an erodible land surface, combined with a strong and frequent wind that provides the dynamic force for erosion. However, according to the self-regulation of the nature and earth surface system, when the system suffers from slight damage it can be self-regulated by its internal feedback mechanism and thereby maintains the stability of the system. So far as we know, desertification resulting from natural causes occurs at a small scale, is of low severity and is reversible.

Based on many studies, we found that aeolian desertification mainly occurred during the human historical period and only developed rapidly in the last century. The changes of natural conditions, mainly from the climatic fluctuations over a century are generally small and is insufficient to cause great changes of the natural environment. However, the rapid increase in human population and disturbance from economic activities in the same period could lead to serious deterioration of eco-environment and rapid development of desertification. Archaeological data and field investigations have shown this (Hou & Yu, 1973; Hou, 1981). When the arid and semiarid region in northern China was occupied by a nomadic society, there was almost no pressure on the eco-environment and land use, but after nomadism was replaced by agricultural production, the environment suffered great damage. Human causes of desertification involve rapidly increasing population, over cultivation, overgrazing, overcutting of fuel wood, over-extraction of groundwater, and poor ecological management, all of which destroy the vegetation which finally leads to wind erosion and aeolian desertification. According to recent studies, man-made disturbance of cover reduces water holding capacity of the soil, suppresses airflow, rise and convergence, enhances surface albedo, intensifies airflow descending and finally leads to aridification. Owing to the biological-geophysical feedback system, the desertification induced by anthropogenic causes brings faster and more severe direct damages than that induced by natural causes (Joseph, 1981; Charnery et al., 1975).

According to field investigations and remote sensing data analysis, among various causes of desertified lands in Northern China, over cultivation contributed to 25.4% of the total aeolian desertified area, overgrazing induced 28.3%; overcutting fuel wood caused 31.8%, water resources misuse and vegetation destruction due to industrial construction resulted in 9%, and sand dune encroachment lead to 5.5% (Zhu, 1985). This indicates that human factors are the most important and most active factor that affects aeolian desertification processes. The human factor cause the changes of land use from rangeland to farmland and burdens the land through over-cultivation, over-grazing, and over-collection of fuel wood. The dramatic destruction of vegetation cover by human activities also accelerates the process of desertification. The human impact can increase wind erosion from 4 to 10 times the natural rate. On aeolian desertified land, the degradation of soil nutrients, bio-diversity, and bio-production can be 3 to 10 times of natural process (Wang et al., 2004).

4 Processes of aeolian desertification

The occurrence and development of desertification are actually the processes of wind erosion, involving the detachment, transportation and deposition of sand by wind. To understand the desertification processes requires knowledge on the occurrence and development laws of surface blown sand activities, such as the dynamics of blown sand movement and the roles of biological processes, and human activities.

4.1 *Dynamic of blown sand movement*

The dynamic of blown sand movement involves the processes of aeolian morphology transformation under wind force, reactivation of fixed dunes, and sand dune migration at desert margins. The processes of morphological transformation under the action of wind force deals with the interaction between wind force and

exposed ground. Under the wind force, sand particles creep, saltate and suspend, and finally form into wind-sand stream, thus initiating the aeolian geomorphological processes of erosion, transport and deposition. Wind-sand stream is formed by the interaction of physical media with different densities, i.e. air and sand (or gravel). Once wind velocity reaches the threshold value, surface particles begin to fly with the wind. That is how sand-bearing wind comes. Sand-carrying wind has a much larger erosion capacity than wind without sand because of the striking and abrasion of sand driven by wind. As a result, wind erosion exacerbates and further leads to topsoil loss, soil quality deterioration, and land productivity reduction.

When wind-sand streams encounters obstacles, the characteristic of the underlying surface changes and the carrying capacity of wind decreases when the wind velocity drops. As a result, particles in the airstream will settle resulting in sand accumulation on land and vegetation. According to the dynamical principle of blown sand movement, accumulated sand is an obstacle to blown sand movement, it causes the separation of the attachment layer and eddy flow and hence reduces near-surface wind velocity and accelerates sand deposition. With further accumulation of sand, shield dune and barchan dunes occur. Reactivation of fixed dunes is attributed to the destruction of primary vegetation on sand dunes and the direct action of sand-carrying wind over sand dune surfaces. It generally appears as such a processes, wind-eroded breaches occur on the windward slope of sand dunes →blowout →deflation cliff →deflation pit →windward slope of deflation pit becomes gentle; in the meantime at the leeward side of the sand dune occur wind deposition processes and appear as spotted shrub-grass sand mound → sand sheet → semifluid sand sheet → moving sand dune and moving shrub-grass sand mound → typical moving sand dune landscape; under the action of wind force sand dunes at the margin of sandy desert migrate, namely exposed sand dunes, or newly exposed fixed dune due to vegetation destruction continuously receive sand supply on the windward slope, or continuous wind erosion on the windward slope, thus resulting in the migration of whole dune body in the prevailing direction. Surface roughness reduction by human-caused destruction of land cover and intensifying blown sand activity are the basic factors affecting the blown sand dynamic processes of aeolian desertification.

4.2 *Biological processes*

Biological processes of desertification are mainly manifested in the degraded succession of vegetation, i.e. evolution of landscape pattern. Studies in recent years have shown that the vegetation succession of sandy grassland is different from that of common grassland and is mostly related to the aeolian desertified land degrees. Vegetation succession stage and desertified degree can be a mutual precondition for each other. Vegetation changes in desert regions contain both gradual and sudden changes, which are controlled by desertified degrees and also depend on the vegetation structure and function. On the different types of desertified land, vegetation changes often appear as a sudden change. On the same type of desertified land, vegetation shows a gradual change under the slight desertification condition, but exhibits a sudden change under the severe desertification condition. However, the degradation form and rate of vegetation often show a significant difference due to different causes. The process of grazing-induced grassland desertification has 3 stages. At the beginning, overgrazing results in a significant decrease in biodiversity, vegetation cover, grass height and grass yield in grassland. Then, if high grazing pressure continues, perennial grasses begin to disappear at first, and then palatable annual grasses. Eventually, grassland will be dominated by unpalatable grasses or toxic grasses. That's how grazing-induced grassland desertification happens. When vegetation cover reduces, a certain degree of small bare spots occur on the grassland. With continuous expansion of disconnected bare spots, the entire grassland eventually turns into desertified land. Grassland desertification processes caused by wind erosion and water shortage are generally similar to those caused by grazing. However, there are also some differences, they are mainly manifested in such a fact that from shady slope to sunny slope, from wetland to dryland, and from fixed sand land to mobile sand land the vegetation worsens rapidly. Furthermore, the degradation is significantly faster than that caused by grazing and both vegetation cover and plant species decrease rapidly but vegetation height and output do not necessarily decrease (Zhao et al., 1999). Under favorable environmental conditions degraded vegetation on sand land may occur positive succession; plant species, vegetation cover and height increase significantly, and the percentage of herbs in the communities also increase (Zhao et al., 1998). Although vegetation degradation in a desertified region mainly results from human activities, the ecosystem has self-restoration capacity,

once human disturbances are removed, plants in inter dune depression or coppice dune areas will invade surrounding regions and gradually restore the original landscape.

4.3 *Anthropogenic processes*

As described above, aeolian desertification is land degradation and human economic activities are the main factor responsible for such a process. In arid, semiarid and sub-humid regions in China, the climate is dry, precipitation is sparse and highly variable, strong wind is frequent, the environment is harsh and the ecological condition is fragile. In addition to this, people's education level is low, production is backward under poor economic conditions and land productivity is low. Hence it has a lower population carrying capacity.

With an improvement of people's living standard and public health service, population rapidly increases and exerts increasingly greater pressure on the land. To feed the increased population, vegetation is cleared to extend cropland and to get firewood. Under harsh natural condition, unprotected lands by vegetation are impossible to restore to the original landscape. Once overgrazing, strong cultivation and industrial construction occur in the grassland region, grasses gradually degrade and bare spots occur on surface. During drought and strong wind periods such land is highly vulnerable to erosion, and may cause reactivation of sand dunes. As a result, soil becomes coarse and impoverished, water capacity and soil moisture content drop, original forest and grassland landscape is finally replaced by desert. Therefore, the climate becomes drier and desertification is further exacerbated. Hence, anthropogenic process of desertification is a vicious cyclic process.

5 Negative influence and their assessment of aeolian desertification

Although present assessments on aeolian desertification damages are mostly qualitative, it is important to understand the issues and to enhance people's urgent feeling for combating desertification. The disastrous influence of aeolian desertification on the environment and the socio-economy mainly includes the following: (1) damaged ecological balance, worsened environment, lowered land productivity, threatened people's livelihood, aggravated poverty and perhaps ecological refugees, (2) loss of usable land resources and decreased human's living space, (3) threatened the safety and normal operation of communities, traffic lines, water conservancy projects and national defense bases, (4) caused a direct economic loss of 54 billion RMB each year (Zhang et al., 1996) and (5) sand and dust storms, as a mark and sudden event of aeolian desertification, became more frequently and stronger. The increased dust storm frequency coincided with the spread of aeolian desertified land in China. For example, a dust storm in 1993 resulted in a direct economic loss of 540 million RMB. During the spring of 2000, about 12 strong sand-raising events and dust storms have hit Northwest China and to a certain extent affected large areas of Eastern and Southern China, such as Beijing, Tianjin, Nanjing and Shanghai etc. The severe sand storms in 2000 were not only related to the passage of a cold air mass but also caused by the expansion of aeolian desertified land and the aggravation of the degree of desertification.

Further research is required in the assessment of desertification damages. It is generally accepted that some indicators concerning natural conditions and socioeconomic regimes are useful to reflect the influential degree of desertification. However, there is still no indicator system established for global application. According to the actual situation in China, we have put forward a general aeolian desertification indicator and severity classification system to assess the state and trend of desertification, of which surface morphological change is a primary indicator, and other changes in soil, vegetation and ecosystem are also considered. For the monitoring and assessment of aeolian desertification in vast regions in Northern China, the selected indicators should be representative. Surface morphological change resulting from wind erosion in the desertification processes has such a character, is also an evident landscape indicator. Many other factors such as vegetation cover, plant community structure, plant species, biomass, soil grain-size composition, organic matter content and soil moisture content are also directly related to surface morphological changes, hence they can be used as additional indicators.

We classified various assessment indicators of desertification as follows: (1) Natural indicators include the area changes of wind-eroded land, sand land or sand dune, dust storm frequency, seasonal and annual changes of precipitation, wind velocity and direction, available soil layer thickness, groundwater level and quality and surface albedo etc., (2) biological and agricultural indicators include vegetation cover, biomass, dominant plant species and distribution, land use states (for example, farming, grazing, fuel wood, industry, mining and water

resource etc.), crop yield, livestock composition and number, and various economic inputs, and (3) social and economic indicators including industrial structure, input benefit, population number and structure changes and developmental trend, public health indexes, mandatory plans and special policies.

6 Practice in combating aeolian desertification

China has made much progress in understanding and combating the process of desertification since the 1950s. Many projects have been carried out.

According to the natural and economic conditions of arid and semiarid regions and aeolian desertification developmental trend in Northern China as well as some typical experiences of aeolian desertification control, the fight with aeolian desertification should balance the ecological, economic and social benefits. It should also follow the ecological principles of moderate utilization and multi-complementation to contain land use during the process of controlling desertification (Wang, 2004). In order to improve the ecosystem of the whole arid and semiarid regions we should work out an overall planning and adopt comprehensive control strategies. With respect to economic development, diversity of the forestry economy should be improved, meanwhile population growth should be effectively controlled. The arrangement of control projects can be divided into three steps, i.e. firstly, experiment and research to find an efficient way to control aeolian desertification; secondly, a demonstration area to examine the efficiency of utilized aeolian desertification control techniques; and lastly, the practice and promotion of successful techniques; In the mixed farming-grazing region where residential area, cropland and grassland are scattered, measures as prohibiting grazing, readjusting rainfed farming-dominated land use structure, increasing forest and grassland area, intensive management to the land with better water and fertility conditions, establishing farmland forest net and patchy forest (shrub) in interdune depressions are adopted in the household base to control aeolian desertification spread and to stimulate economic development. In the grazing grassland, a rational stocking and rotational grazing system should be established. In addition, efforts should be made to construct an artificial grassland and forage base, rationally arrange drinking water wells, define grazing density and build a road system. In the arid zone, an overall planning should be worked out with the basin as an ecological unit, to formulate a reasonable water allocation plan, construct farmland forest net inside oases and sand-proof a tree-shrub belt around the oases, in combination with mechanical sand fences and sand-fixing plants inside sand fence grids to form a protective system. In addition, the transport lines in the dense sand dune regions should be protected by mechanical sand fences and sand-fixing plants.

The Chinese government promulgated *Law of the People's Republic of China on Prevention and Control of Desertification* in 2002, which is the first and the only national law in the world up to now. This national law provides all the desertification control project legitimate support from planning to completion.

Since the implementation of the Western Development strategy, China has made the desertified region a top priority for ecological construction. Since 2000, the central government has invested a total arrangement of 217.22 billion RMB, and has implemented a series of ecological construction projects, such as the project of Natural Resources Conservation, the project of Returning Farmland to Woodland or Grassland, the project of Sandstorm Source Control surrounding Beijing and Tianjin Area, the project of the Three-North Shelterbelt System Construction, the project of Wildlife Protection and Nature Reserve Construction, and the project of Wetland Protection and Restoration, etc. These projects greatly contributed to the western region's ecological protection and construction process. Forest coverage in the western region in 2008 had reached 17.05%, compared with 10 years ago, and it increased by 6.73%.

According to the State statistics, in the past 10 years since the implementation of the western development strategy, the western region totaled 30.65 million ha of forests planted. According to the seventh national forest resources inventory data issued on January 28, 2010, forest reserves in the western region amounted to 8.27 billion m^3. Compared with the fifth inventory in 2000, the forest reserves increased by nearly 1.3 billion m^3. The increases of forest cover effectively controlled soil erosion and aeolian desertification. Shaanxi, Gansu, Ningxia, Inner Mongolia and other provinces across the country first achieved the historic change from the "sand advances and human retreating" to the "human advancing and sand retreating". In Mu Us Sandy Land, aeolian desertification status has achieved a fundamental change and began to enter a new phase of control and using this Sandy Land. About 0.15 million km^2 of soil erosion on the Loess Plateau were controlled and annual silt and sand sediment into the Yellow River was reduced

more than 300 million tons (Gao et al., 2009).

For the last 10 years, the Central Government has dedicated 10 billion RMB in total to wildlife protection, and state-level nature reserve construction projects. Forestry sectors had built 395 new nature reserves with an area of 39.72 million ha in the western region, and had formed a network of nature reserves system preliminarily. The Central Government had implemented 55 wetland protection and restoration projects in the western region, and effectively protected an area of 6.59 million ha of wetlands. In forestry ecological construction in the western region, the forestry sector insisted to combine forestry and water conservation with combating poverty, and gradually formed a timber cultivation, features economic forests, flowers, deep-processing of wood and bamboo resources, eco-tourism and other advantages characteristic forestry industries, and realized the priority of ecological benefits, and the harmonization of economic and social benefits. The forestry industry output value in the western region reached 294.02 billion RMB in 2008, an increase by 2.6 times that in 1999. Based on the success of the pilot, the Central Government established the forest ecological benefit compensation fund which gives support for the western region in the compensation area and funding arrangements. Until 2009, the Central Government had compensated 44 million hectares of focus public forest in the western region, and cumulatively arranged the forest ecological benefit compensation fund of 11.17 billion RMB. Since 2010, the Central Government will improve the subsidiary criteria of national-level public forest from 75 RMB to 150 RMB per ha every year.

The biggest National Project is the "Grain for Green Program" (1997–2012) and 1,060 counties in 22 provinces have been included in this project. The objective is to withdraw 3.67 million ha of dry land farming and degraded steppe, and 5.13 million ha of aeolian desertified land suited to reforestation and revegetation will be rehabilitated at the end of the Program. There are about 8 million ha of lands under the threats of aeolian desertified land that will be brought under control in the next ten years and 26.67 million ha of windbreaks will be planted. The total financial input is estimated to be 75 billion RMB (11 billion US$) which is entirely from the central government.

Thanks to many efforts from central and local governments, local people in the aeolian desertified regions for many years, and aeolian desertification has been reversed as shown by the decrease of 1,375 km^2 annually during the last 10 years.

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