Sandy desertification in the north of China

WANG Tao (王 涛)[1], ZHU Zhenda (朱震达)[1] & WU Wei (吴 薇)[2]

1. Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China;
2. Center of Environmental Sciences, Peking University, Beijing 100871, China
Correspondence should be addressed to Wang Tao (email: wangtao@ns.lzb.ac.cn)

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Abstract With the economic and social development, desertification exerted increasingly profound influences on natural environment and social development and attracted widespread attention of international communities. China, as one of the countries facing severe desertification problems, has witnessed some progress in understanding and combating the process of desertification through many years of hard work. Based on the experiences and research achievements, this paper briefly discusses the causes, developmental processes, damage assessment and control mechanism of desertification in the north of China so as to provide some basic experiences for the further study of desertification.

Keywords: desertification, cause and process, damage assessment, desertification control.

Desertification problem caused by inharmony between environment and development not only results in the destruction of resource-environment system and poverty, but also affects the social stability and economic development. Therefore, it has attracted widespread attention of international communities. China is one of the countries suffering from severest desertification in the world; especially the rapid development of desertification and its tremendous influences on the environment, society and economy have received considerable attention. Desertified lands in China are mainly distributed in the arid, semiarid, and part of sub-humid regions of the north of China, including the Inner Mongolia, Ningxia, Gansu, Xinjiang, Qinghai, Tibet, Shaanxi, Shanxi, Hebei, Jilin, Liaoning and Heilongjiang. According to the actual situations in China and the studies over the past 20 years, we defined the sandy desertification as a land degradation characterized by wind erosion mainly resulting from the excessive human activities in arid, semiarid and part of sub-humid regions. Modern desertified lands in China cover a total area of $38.60\times10^4\,km^2$ and form a discontinuously distributed arcuate-belt from Northeast China to North China and to Northwest China. Of this total area, 29% is distributed in the mixed farming-grazing regions and 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 region of Hebei Province and Houshan region in Inner Mongolia) with wind erosion and sand sheet as the striking features; 44% is distributed in the middle and western parts of semiarid zone and desert steppe zone (mainly in the middle of Inner Mongolia) with reactivated fixed dunes and shifting sand spread as the main features; and 27% is distributed at the margin of oases in arid zone and lower reaches of inland rivers

(mainly in the Alxa region of west Inner Mongolia, northern part of Hexi Corridor region in Gansu and lower reaches of the Tarim River in Xinjiang) with reactivation of fixed dunes as the main feature. In the last 50 years, desertified land expanded with an increasing annual rate. The annual expansion rate was 1560 km^2 from the late 1950s to the mid-1970s; 2100 km^2 from the mid-1970s to the late 1980s[1]; and 3600 km^2 during the 1990s. Rapid expansion of desertified land not only seriously endangers the eco-environment and socio-economic development but also greatly hinders the ecological construction of the 21st century and the implement of the development of the West in China, especially hampers the development and the improvement of people's living standard in the desertified regions.

Shortly after the 1977 United Nations Conference on Desertification, China officially launched multidisciplinary and comprehensive research to combat "desertification". Over the last 20 years, researchers have made some encouraging progress in this study field, and much work was conducted in the regions with fragile eco-environmental conditions and frequent human activity from the angle of man-land relation[2—9]. Through remote sensing monitoring of desertification with field investigation in large regions[9—14], we have achieved a preliminary understanding to the desertification and also solved some problems such as the causes, distribution, types and damages of land desertification in the north of China[15—18]. Through multidisciplinary research of desertification developmental processes including blown sand dynamic processes, biological processes and anthropogenic processes, the roles of human and natural impact on the desertification development processes have been established and a multi-level comprehensive indicator system of desertification with blown sand activity as the main indicator has been put forward. In this paper we will give a brief discussion on several important problems including the sandy desertification causes, processes, damage assessment and control measures etc.

1 Sandy desertification cause

Sandy desertification is a land degradation process of land productivity diminution, land resource loss, and desert-like landscape occurrence in arid, semiarid and part of sub-humid region. Its cause has always been a basic subject in the research. Only when the cause of desertification is correctly understood can we put forward effective control measures and thoroughly solve the degradation problem. In fact, we can divide the desertification cause into two categories, namely natural cause and human cause.

1.1 Natural cause

Natural occurrence and development of desertification is a common phenomenon in arid and semiarid regions of China. For example, wind erosion and moving dune encroach on the oases, river terraces and natural vegetation destruction in the wind gap area. Sandy desertification mechanism of natural cause can be summed up as two points: (1) global climate change, especially the climatic warming and aridification in the mid-latitude regions is a major ecological background favorable for the development of desertification; and (2) the presence of some adverse

factors such as dry climate, erratic precipitation, sandy soil texture, erodible land surface, especially the strong and frequent wind provides dynamic force for the erosion. However, there always exists a certain self-regulating capacity in the nature and earth surface system. Once 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 cause often has a small scale, low severity and can be easily reversed.

1.2 Human cause

According to many studies, we find that the sandy desertification mainly occurred during the human historical period and developed rapidly for the last century. The changes in natural conditions, mainly the climatic fluctuations over a century are generally small and therefore insufficient to cause great changes of natural environment. However, rapid increase in human population pressure and disturbance of economic activities to environment in the same period could lead to serious deterioration of eco-environment and rapid development of desertification. Many archaeological data and field investigations have proved this. When the arid and semiarid regions in the north of China was occupied by nomadic people, there was almost no pressure on the eco-environment and landuse, but after the nomadism was replaced by agricultural production the eco-environment suffered from great damages. It is generally accepted that human causes including rapidly increasing population induced over cultivation, overgrazing, overcutting fuelwood, over-extracting groundwater and poor ecological management way, destroy the landcover and finally lead to wind erosion and sandy desertification under. According to recent studies, man-made destruction of ground cover reduces soil water-holding capacity, suppresses airflow rise and convergence, enhances surface albedo, intensifies airflow descending and finally leads to climatic aridification. Owing to the influences of biological-geophysical feedback mechanism, the desertification induced by anthropogenic cause can bring much more fast and severe direct damages than that induced by natural cause.

According to field investigations and remote sensing data analysis, among various types of desertified lands in the north of China, over cultivation-induced sandy desertified land area occupied 25.4% of the total sandy desertified area, overgrazing-induced 28.3%; overcutting fuelwood-induced 31.8%, desertified land caused by misuse water resources and vegetation destruction due to industrial construction occupied 9% and resulting from sand dune encroachment occupied only 5.5%. From the above data, we can say that the human factors are the most important and most active factors affecting sandy desertification processes.

2 Occurrence and development processes of sandy desertification

The occurrence and development processes of desertification are practically the processes of blown sand erosion, transport and deposition due to upset of ecosystem balance by human activities and vegetation degradation or disappearance. The study of desertification processes requires elucidating the occurrence and development laws of surface blown sand activities; it mainly con-

tains such research contents as dynamics of blown sand movement and the roles of biological and human activities.

2.1 Dynamical processes of blown sand movement

The dynamical processes of blown sand movement mainly contain the development processes of sandy surface morphology under wind force, reactivation of fixed dunes and sand dune migration at the margin between sandy desert and oases.

The development processes of sandy surface morphology under the action of wind force deal with the interaction between wind force and exposed ground surface. Under the wind force, surface particle creep, saltation and suspension take place and form wind-sand stream, thus initiating the aeolian geomorphological processes of erosion, transport and deposition. Wind-sand stream is formed by the interaction of two different densities of physical media, i.e. air and sand (or gravel). Once wind velocity reaches the threshold value, surface particles begin to move and form sand-bearing wind to further abrade and erode surface.

As a result, soil wind erosion exacerbated and thus leads to topsoil loss, soil quality deterioration and land productivity reduction. When wind-sand stream encounters obstacles, the character of underlying surface changes and sand-bearing wind becomes saturated; its velocity drops and many of the particles in airstreams will settle and result in sand accumulation land and vegetation. According to the dynamical principle of blown sand movement, accumulated sand is in fact an obstacle to blown sand movement. It causes the separation of attachment layer and eddy flow and hence reduces near-surface wind velocity and quickens sand deposition. With further accumulation of sand, shield dune and barchan dune occur. Reactivation of fixed dunes is attributed to the destruction of primary vegetation on sand dunes and the direct action of sand-bearing wind over sand dune surface. It generally appears as such a process: wind-eroded breaches occur on 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 sand dune wind deposition processes occur 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 caused by human destruction of landcover and intensifying blown sand activity are the basic factors affecting the blown sand dynamical processes of sandy desertification.

2.2 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 show that the vegetation succession of sandy grassland is different from that of common grassland and it is mostly related

to the sandy desertified land degrees. Vegetation succession stage and desertified degree often constitute each other's precondition[19]. Vegetation changes in desert regions contain both gradual and sudden changes, which are controlled by desertified degrees and also depend on their own 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[20]. However, the degradation form and velocity of vegetation often show a significant difference due to different causes. For grazing-induced grassland desertification, its degradation law is: significant decrease in biodiversity, vegetation cover, grass height and grass yield; perennial grasses firstly go out of the grassland, followed by palatable annual grasses and finally the grassland will be dominated by unpalatable grasses or toxic grasses. When vegetation cover reduces, a certain degree of small bare spots occur on the grassland surface; with continuous expansion and connection of small bare spots the grassland at last entirely turns into desertified land[21—23]. Grassland desertification processes caused by wind erosion and water shortage are generally similar to those caused by grazing. However, there are also some differences, which 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[24]. Under favorable environment conditions degraded vegetation on sand land may show positive succession; plant species, vegetation cover and height increase significantly, and the percentage of herbs in the communities also increase[25—28]. Although vegetation degradation in 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 in surrounding regions and gradually restore original landscape.

2.3 Anthropogenic processes

As described above, sandy 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, climate is dry, precipitation is sparse and highly variable, strong wind is frequent, environment is harsh and ecological condition is fragile. In addition to this, people's education level is low, production way is backward under poor economic conditions and land productivity is low. Hence it has lower population carrying capacity. Along with the improvement of people's living standard and public health service, population rapidly increases and exerts increasingly greater pressure on land. To feed more and more population, people clear vegetation to extend cropland and to get fuelwood. Under local harsh natural condition, unprotected lands by vegetation are impossible to restore their original landscape. Once overgrazing, strong cultivation and industrial construction occur in the grassland region, grasses gradually degrade and bare spots occur on sur-

face. During drought and strong wind period such land is highly susceptible to be eroded, further form shifting sand and cause reactivation of sand dunes. As a result, soil becomes coarse and impoverished, soil water-holding capacity and moisture content drop, original forest and grassland landscape is replaced by desert landscape, exposed ground surface cannot prevent erosion by wind but increase albedo. Therefore the climate becomes drier and desertification is further exacerbated. Hence, anthropogenic process of desertification is a vicious cyclic process.

3 Sandy desertification damage and assessment

Although present assessments on desertification damages are mostly qualitative, they have important significance to understanding of desertification issues and to enhancing people's urgent feeling to combat desertification. The assessment of desertification disastrous influence on environment and socio-economy mainly includes the following: (1) Desertification damaged ecological balance, worsened environment, lowered land productivity, threatened people's livelihood, aggravated poverty and even resulted in the ecological refugees; (2) desertification caused the loss of usable land resources and decreased Chinese nation's living space; (3) desertification seriously threatened the safety and normal operation of communities, traffic lines, water conservancy projects and national defence bases; (4) desertification caused a direct economic loss of 54 billion Chinese yuan each year; (5) sand and dust storms as a mark and sudden event of desertification become more frequent and stronger. According to statistical data[1)], annual dust storm frequency in recent 50 years in China showed an increasing tendency. For example, strong dust storms occurred 5 times per year in the 1950s; 8 times in the 1960s; 13 times in the 1970s, 14 times in the 1980s and 23 times in the 1990s. The increase in dust storm frequency coincided with the spread of sandy desertified land in China. Only a single strong dust storm in 1993 resulted in a direct economic loss of 540 million yuan. In the spring of 2000, about 12 strong sand-raising events and dust storms have hit the northwest of China and even to a certain extent affected large areas of east and south of China, in clouding Beijing, Tianjin, Nanjing and Shanghai etc. Their occurrence is not only related to the passage of cold air mass but also related to the expansion of desertified land and the aggravation of desertification degree.

Further research is required in the assessment of desertification damages. It is generally accepted that some indicators concerning natural conditions and socioeconomic regimes should be established to reflect the influential degree of desertification. However, at present there is still no consistency in the indicator and application and a global unified indicator system has not been established. According to the actual situation in China we have put forward a general sandy desertification indicator and severity classification system to assess desertification state and trend, of which surface morphological change is a main indicator. In the meantime other changes in soil,

1) State Forestry Bureau, Northwest China Investigation Group, Investigation report on great development of west China and propagation of green homeland construction, 2000.

vegetation and ecosystem are also considered. For the monitoring and assessment of sandy desertification in vast regions in the north of China, the selected indicators should be representative. That 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, landuse states (for example, farming, grazing, fuelwood, industry, mining and water resource etc.), crop yield, livestock composition and number, and various economic input etc. (3) Social and economic indicators include industrial structure, input benefit, population number and structure changes and developmental trend, public health indexes, mandatory plan and special policy etc.

4 Sandy desertification control

According to natural and economic features of desertified regions and desertification developmental trend in the north of China as well as some typical experiences in desertification control, the rehabilitation of desertified land should thoroughly consider the ecological benefit, economic benefit and social benefit. It should also follow the ecological principles of moderate utilization and multi-complementation to contain landuse in the control processes[29]. In order to improve the ecosystem of the whole arid and semiarid regions we should work out an overall planning and adopt comprehensive rehabilitation strategies. In the respect of economic development the principle of diversified economy dominated by forestry should be practiced; in the meanwhile population growth should be effectively controlled. The arrangement of rehabilitation projects can be divided into three levels, i.e. research organizations mainly undertake desertification control experiments in the experimental plots; research organizations in cooperation with production departments conduct experiments in the demonstration plots; production departments and local people popularize successful techniques. In the mixed farming-grazing region where residential area, cropland and grassland are scatteredly distributed, with ecological household as a unit such measures as prohibiting grazing, readjusting rainfed farming-dominated landuse 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 to control desertification spread. This also contributes to economic development. In the grazing grassland a rational stocking rate and rotational grazing system should be established. In addition, efforts should be made to construct artificial grassland and forage base,

rationally arrange drinking water wells, define grazing density and build roads. In the arid zone an overall planning should be worked out with basin as an ecological unit, to formulate rational water allocation plan, construct farmland forest net inside oases and sandbreak tree-shrub belt around the oases, in combination with mechanical sand fence and sand-fixing plants inside sand fences grids to form a perfect protective system. In addition the transport lines in the dense sand dune regions should be protected by mechanical sand fences and sand-fixing plants, laying emphasis on fixation in combination with block.

Through a series of experiments on different desertification control models in several experiment plots the following successful examples have been found.

Example 1. Sandy land transformed into plastic film-bottomed rice field in Naiman Banner of Inner Mongolia

Sandy desertified land in Naiman Banner occupies 57.6% of its total area, being a typical desertified area in the north of China. Owing to dry climate and serious blown sand disaster agricultural and livestock production outputs are low and instable, especially the food problem has seriously hindered local economic development. Through many years of exploration and experiments, scientists and local people have successfully developed a rice cultivation technique in plastic film-bottomed sandy land and thus create a new way to control shifting sand. This technique has proved to have a bright future. The total areas of sandy desertified land had decreased from 5410 km^2 in 1987 to 4500 km^2 in 2000.

Example 2. Sand stabilization by *Pinus sylvestris* in Zhangguotai Sandy Land of Zhangwu County in Liaoning Province

Zangguotai is located at southeastern part of the Horqin Sandy Land. In view of serious blown sand disaster in the region, since 1952 local people have launched sand stabilization, afforestation and species introduction works. Since then *Pinus sylvestris* has been successfully used in moving dune stabilization. Up to now, some 2130 hm^2 of *P. sylvestris* forest have been planted in the demonstrative plots and popularized over 3000 hm^2 in another 6 pilot experiment plots. Long-term observations have proved their obvious ecological benefit, economic benefit and social benefit. Besides Liaoning and Inner Mongolia, *P. sylvestris* has also been introduced in the north and northwest of China. In addition, each year about 1000 kg seeds and 30 million seedlings of *P. sylvestris* are transported from the demonstrative and pilot plots to “Three-North Region” to be used for the construction of protective forest system.

Example 3. “Four-in-one” household ecological economy in Yutiangao village, Ongniud Banner, Chifeng city, Inner Mongolia

Ongniud Banner, located at the middle of Inner Mongolia and western margin of Horqin Sandy Land, is a part of Horqin Sandy Land. Dry climate, sparse precipitation and frequent blown sand disaster pose a serious threat to local economic development and people’s livelihood. In order to shake off poverty, local people launched vegetable production using solar energy in winter in 1992 and later created a “four-in-one” household eco-economic pattern. It has proved to be an

effective way to control blown sand damage and to help people to shake off poverty.

Example 4. "Advance One-Retreat Two-Return Three" sand control strategy in Houshan region, Ulanqab League, Inner Mongolia

Ulanqab League, located to the north of the Yinshan Mountain, includes Huade County Shangdu County, Qahar Youyi Middle Banner, Qahar Youyi Rear Banner and Siziwang Banner. Owing to dry climate, frequent blown sand disaster, severe desertification, impoverished soil and irrational industrial structure[30], agricultural output in these regions are low, per capita grain share has decreased from 535 kg/a to 272 kg/a, per capita income is about 200 yuan. After the National Conference on Sand Control was held in 1991, desertification control in the Houshan region of the league was included in the list of the county's 20 key projects. Local government practiced the "advance one-retreat two-return three" strategy and quickened the comprehensive control pace of land desertification, thus creating a new way to improve the eco-environmental condition of desertified region and to shake off poverty.

Example 5. Constructing farmland through washing sand dunes away by water in Yulin region of Shanxi

Yulin region is located at the southern margin of Mu Us Sandy Land and includes 7 counties. Natural condition in the region is harsh, with serious blown sand disaster. Local economy is backward and people live in poverty. Through 10 years of hard work, 937.5 km^2 of blown sand land were reclaimed by diverting water and washing sand dune away method. Of this total area, newly reclaimed farmland occupied 10^4 hm^2, soil conservation land 97×10^4 hm^2 and artificial grassland 4×10^4 hm^2. After 10 years of reclamation, vegetation cover increased from 24.5% to 74.3%, per capita grain share increased from 428 kg to 1861 kg, livestock number increased from 137000 heads to 175000 heads, and per capita income increased from 497 yuan to 1045 yuan. The former barren desert has now been changed into fertile land.

5 Conclusion

As described above, sandy desertification is land degradation in arid, semiarid and sub-humid regions due to the destruction of man-land system balance by human irrational economic activities to such a degree that the system cannot be rapidly restored by its self-organization and feedback mechanism, as a result, various environmental elements degrade and original sparse-tree sandy grassland landscape turns into desert landscape dominated by blown sand activity.

It can be said that the development process of sandy desertification is a dynamical evolution process of various internal elements of the man-land system and the flow of mass, energy and information of external environment in arid region and finally result in the structural and functional changes of the system. In order to halt sandy desertification, mankind must actively regulate its own activity, form self-adaptability, establish an interdependent and mutual coordination man-land relation, and optimize the structure and function of man-land system to reach a new balance and realize a benign cycle[31].

Owing to its tremendous impacts on economy, environment and politics, desertification has attracted world attention. With the economic development and the increase of social demand, the pressure on natural resources and eco-environment is increasing, coupling with the influence of global change, desertification is posing a serious threat to mankind existence. Hence, there is urgent need to understand the mechanism of desertification occurrence and development and to combat desertification. Although scientists have preliminarily understood the causes and processes of desertification and found out some effective measures to control desertification., there are still many questions to be settled. This is because desertification study deals with natural, social and economic issues and belongs to a multidisciplinary research field. It may be said that desertification study is facing unprecedented challenge and opportunity and great effort should be done in this respect.

For those reasons we suggest the following several research priorities:

(1) Study on natural and human background of desertification. It includes natural environmental background; temporal and spatial changes and mechanism of desertified land over the past 2000 years; desertified land use and coverage change, process, cause and topsoil feature in recent 50 years; positive and negative influences of natural factor and human effect and their respective contributions.

(2) Study on desertification dynamical process and its control. It includes physical process and mechanical principle of desertification; soil wind erosion law and its control, mechanical mechanism of blown sand movement; mechanical model and relation of different scales of sand bodies; mechanical principle and numerical imitation of sand control engineering design; dynamical mechanism of sand and dust storms; predication model of soil wind erosion and tolerance limit; indicator system and regionalization for quantitative assessment of soil wind erosion; dust emission simulation and test from source area; dust transport route, affecting extent and climate-environment effect; frequently occurring area of dust storms, climatic cause, formation and development mechanism; dust-storm monitoring, prediction and early warning methods.

(3) Biological process of desertification and vegetation re-establishment mechanism includes water consuming law of main plant species; water cycle; stress-resistant mechanism, adaptive strategies and vegetation stability; water balance dynamics in typical regions; and suitable scale of vegetation construction.

(4) Comprehensive control strategies and models of desertification. It includes cause, state and developmental trend of desertification in northern China; water and land resource carrying capacity and safe landuse pattern in typical region; comprehensive control strategies and regionalization of desertification and dust storms in northern China; harmonious development strategies and patterns of society, economy and environment in desertified regions; comprehensive control optimization models of desertification and technical experiment and demonstration study.

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