LAND DEGRADATION & DEVELOPMENT

Land Degrad. Develop. **16**: 367–376 (2005)

Published online in Wiley InterScience (www.interscience.wiley.com). **DOI**: 10.1002/ldr.667

DESERTIFICATION IN NORTH CHINA: BACKGROUND, ANTHROPOGENIC IMPACTS AND FAILURES IN COMBATING IT

Y. CHEN[1] AND H. TANG[2]*

[1]*Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China*
[2]*College of Resources Science & Technology, Key Laboratory of Environmental Change and Natural Disaster, the Ministry of Education of China, Beijing Normal University, Beijing, 100875, China*

Received 17 June 2004; Revised 4 October 2004; Accepted 24 October 2004

ABSTRACT

Desertification in north China is ongoing despite the endeavours to mitigate it over the past 50 years. Overall examination of the context of desertification and defects of desertification-combating programmes is a prerequisite for desertification control, which is now attracting general concern in China. The physiographic circumstances of north China, including the dry, continental, mid-latitude climate, easily erodible soil surface and water shortage, provide the background to desertification. Climatic aridity and the evolution of land use and land management in recent decades have produced great stress on the land. The ineffectiveness of anti-desertification measures ascribed to inadequate scientific involvement in decision-making, neglect of the human dimension and the lack of a well-organized desertification monitoring system are discussed in this paper. Copyright © 2005 John Wiley & Sons, Ltd.

KEY WORDS: desertification; combating desertification; land degradation; water deficiency; sustainability; north China

INTRODUCTION

Desertification, defined in the Convention to Combat Desertification and Drought in 1994 as ‘Land degradation in arid, semiarid and dry sub-humid areas resulting from various factors including climatic variability and human activities’, began long ago. It will most likely become the greatest threat confronting humanity in the future because it diminishes the Earth’s capacity to support human beings as the global population increases steadily. China, the most populated country in the world, is now experiencing severe desertification over large areas (Sheehy, 1992; Zha and Gao, 1997; Mitchell *et al.*, 1998). The problem was considered to be an important cause of the increase in dust-storm frequency in north China during 2000 (Ye *et al.*, 2000).

Investigation of China’s deserts and sandy lands began in the late-1950s (Zhu, 1989). At the same time, the control and reclamation of desertified land was initiated by both the Chinese Government and the Chinese People. As a result, some mobile dunes were fixed and vegetation cover was recovered in some areas, such as in Mu Us Sandy Land, Horqin Sandy Land, Hulun Buir Sandy Land and the Tengger Desert (Fullen and Mitchell, 1994; Zhong, 1998; Runnström, 2003; Wang *et al.*, 2004). To date, however, success has been achieved only in a few local areas while the situation in most regions has deteriorated with an escalating rate of desertification in some

*Correspondence to: H. Tang, College of Resources Science & Technology, Beijing Normal University, 19 Xinjiekouwai Street, Beijing 100875, People’s Republic of China.
E-mail: tanghp@bnu.edu.cn

Contract/grant sponsor: National Natural Science Foundation of China; contract/grant number: 40201006.
Contract/grant sponsor: Knowledge Innovation Project of the Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences; contract/grant number: CXIOG-A04-04.

severely desertified places (Fan and Zhou, 2001; Wang *et al*., 2004). How can this dilemma be resolved? Considering its huge population, rehabilitation of China's degraded lands is very important, but narrow desertification-control strategies mask the complex nature of the problem. Desertification is a multifaceted and complex environmental issue that occurs because of a variety of natural and human-made stresses (Wallace, 1994; Gray, 1999; Warren, 2002). So far, analyses addressing different aspects of desertification in north China are discrete and fail to provide sound knowledge about the process. A profound analysis of the causal mechanisms of desertification in north China involving information from various fields should be instituted as part of a national desertification-combating campaign in the twenty-first century. Awareness of the role of humanity in desertification will justify the necessity to regulate human activities in order to prevent desertification. In this paper, we present an analysis of physiographic conditions and anthropogenic land degradation, as well as unsuccessful experiences in combating desertification. This work should lead to a deeper and more robust understanding of China's desertification and the promotion of more appropriate policy involvement.

PHYSIOGRAPHIC CONDITIONS

The arid and semiarid areas of north China with mean annual precipitation of less than 400 mm makes up 30 per cent of the land area in China. It ranges from 35° to 50°N and from 75° to 125°E (Figure 1). The fragility of the ecosystems in these areas is predetermined by inherently harsh physical conditions, such as sparse vegetation, continental climate, sandy soils and water deficiency, which make them prone to desertification.

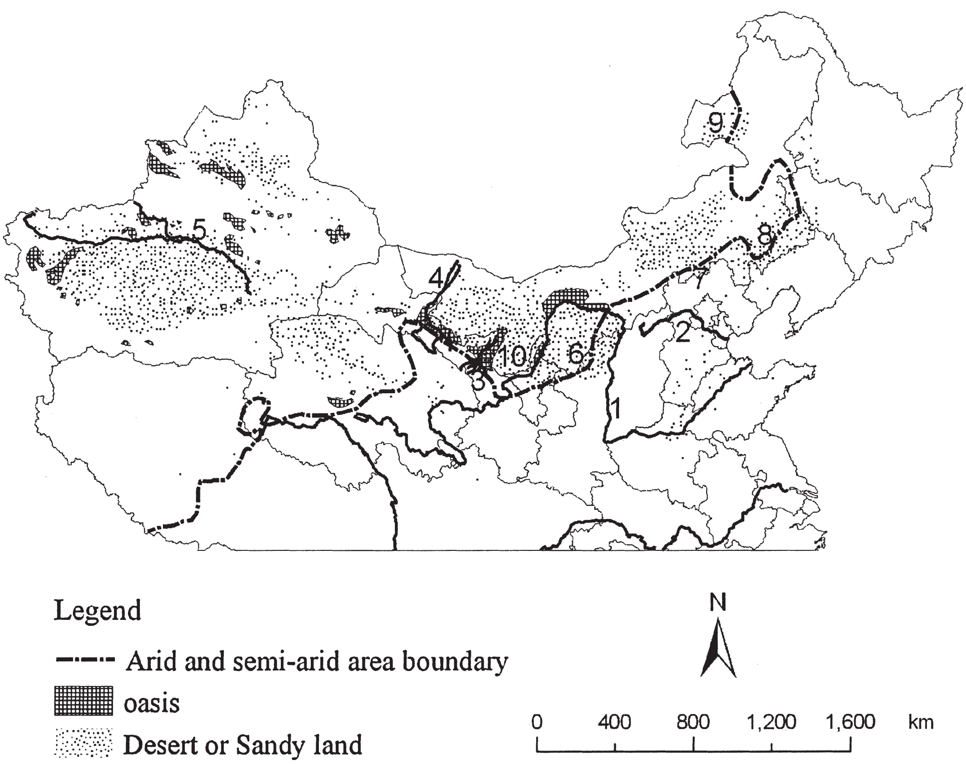

Figure 1. Distribution of oases (after Shen *et al.*, 2001), deserts and sandy lands and some rivers in north China mentioned in the text. 1. Yellow River, 2. Haihe River, 3. Shiyang River, 4. Ruoshui River, 5. Tarim River, 6. Mu Us Sandy Land, 7. Bashang area, 8. Horqin Sandy Land, 9. Hulun Buir Sandy Land, 10. Tengger Desert. The arid and semiarid area boundary after Ci (1994).

Climate Variability

The geographical position of arid and semiarid areas of north China determines the dry mid-latitude climate, which is dominated by continental polar air masses for much of the year (Strahler and Strahler, 1983). The climatic continentality of north China is prominent because of the large distance from the open sea and the weak marine influence due to mountain ranges on the east and southwest (Domrös and Peng, 1988). Most rainfall occurs in summer as a result of sporadic invasions of maritime air masses and therefore annual precipitation in these areas varies wildly. The wettest years receive several times more rainfall than the driest years. Another pronounced feature of the climate of north China is the frequency of high wind during the long and dry seasons of winter and spring when vegetation is withered and shrunk. This situation greatly facilitates wind erosion of sandy surface. There are 30–210 days a year in north China when the wind velocity is higher than $5\,m\,s^{-1}$, the threshold velocity required to transport particles of sand and silt, and 20–80 days a year with wind velocities of $20\,m\,s^{-1}$, which can cause severe deflation (Li and Wang, 1988). The wind regime shapes the landscape of north China into progressive transition from gobi, through sandy desert land to loess from northwest to southeast (Fullen and Mitchell, 1994).

The climatic fluctuations in China vary between different areas. Ye and Chen (1992) reported a general trend toward increasing climatic aridity in north China from the 1960s–1990s. A pervasive and significant temperature rise in north China over the past decades was described by many studies (Chen *et al*., 1998; Shang *et al*., 2001). According to Le Houérou's estimate (Le Houérou, 1996), one degree increase in temperature would cause an annual potential evapo-transpiration (PET) rise of approximately 5·25 per cent ± 1·55. During this period, however, rainfall in north China remained average and declined in many areas (Chen *et al*., 1998). For example, mean annual precipitation in Inner Mongolia was constantly under the normal range from 1963 to 2000 (Li, 2001) (Figure 2). As a result, the P:PET ratio would decrease and indicate a rise in land aridity, definitely leading to a reduction in effective soil moisture, a condition necessary for desertification. Nevertheless, this kind of climatic fluctuation causes a trivial effect on desertification, as compared with anthropogenic impacts.

Surface Materials

About 40 per cent of the arid and semiarid areas of north China are desert and sandy land (Zhu *et al*., 1986). Oases occupy less than 3 per cent of the total desert areas (Shen *et al*., 2001) (Figure 1). The deserts in northwest China are dominated by moving sand dunes, with a small percentage of vegetated land. Dunes migrate constantly toward

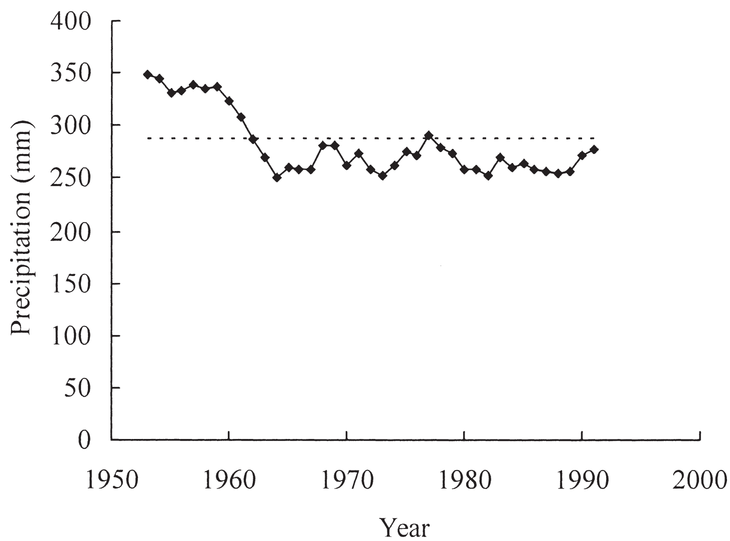

Figure 2. Annual precipitation of Inner Mongolia from 1951 to 1996. The solid line represents 5-year running mean and the dashed line annual mean (after Li, 2001).

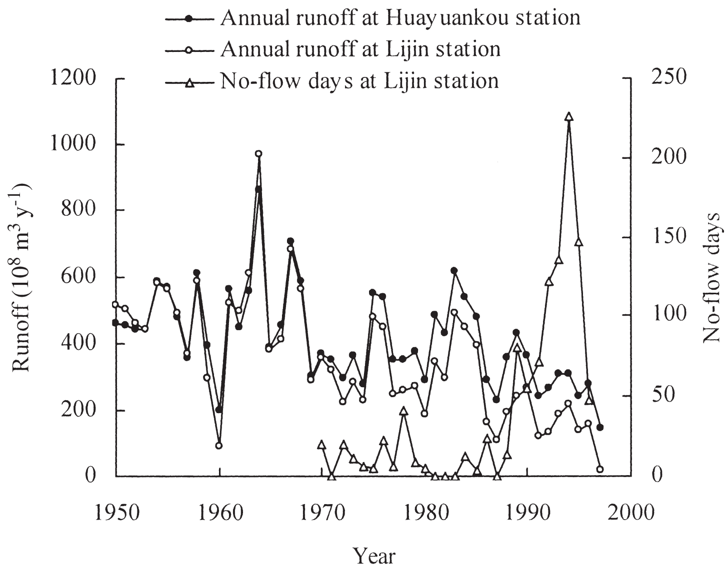

Figure 3. Annual runoff and no-flow days through the lower reaches of Yellow River from 1950 to 1997 (after Li *et al.*, 1993; Xu, 2004).

the southeast due to dominant winds from the northwest (Walker, 1982; Zhu *et al.*, 1986). Desert soils and chestnut soils that contain a large percentage of sand and silt particles, which are susceptible to wind erosion, cover the bulk of north China (Nanking Institute of Soil Science, Academia Sinica, 1980).

Water Deficiency

Water deficiency is a primary problem in arid and semiarid areas. Inadequate rainfall results in a paucity of surface and ground water in north China. For example, the natural average annual discharge of the Yellow River, the second longest river in China, which stretches across northern China, is less than $\frac{1}{16}$th of that of the Yangtze River, the longest river in China. River runoffs in north China are inclined to decrease because of climatic changes and increasing human demands (Ren *et al.*, 2002) (Figure 3). Zero-flow occurred in many major rivers of north China in the 1970s–1980s (Li *et al.*, 1993). Some naturally perennial rivers, such as the lower Yellow River, the lower Yongding River (one of the source rivers of the Haihe River), and the lower Hutuo River (one of the source rivers of the Haihe River) in the North China Plain, have been changed into seasonal rivers (Xu, 2004). The Yellow River had zero-flow for 20 out of 26 years from 1972 to 1997 (Figure 3) and both the length of reach and period of zero-flow became longer during that time (Chen and Mu, 2000). The consequences of zero-flow include land aridity, vegetation diminution and further desertification (Li *et al.*, 1993). Also, a continuous decline in regional groundwater levels occurred (Zhu *et al.*, 2004). Many inland lakes diminished or vanished (Qin, 1999; Ye and Hu, 2000). In numerous regions of north China, such as the Yellow River drainage area (Wang, 1999), the Tarim River drainage area (Li *et al.*, 1993), the Shiyang River drainage area (Li *et al.*, 1993), the Ruoshui River drainage area (Zhu and Chen, 1994), the Haihe River drainage area (He and Wang, 2001), etc., groundwater levels dropped considerably causing vegetation deterioration.

ANTHROPOGENIC IMPACTS ON LAND

Obviously, climate variability alone cannot account for severe desertification in recent decades in north China. The primary causes of current desertification in some areas were identified as intensified and irrational human activities, such as in the Mu Us Sandy Land (Luk, 1983; Wu *et al.*, 1997; Wu and Ci, 2002), the Bashang area (Wang *et al.*, 1991), and the Horqin Sandy Land (Wulan, 2002) (Figure 1). More intensive exploitation of natural

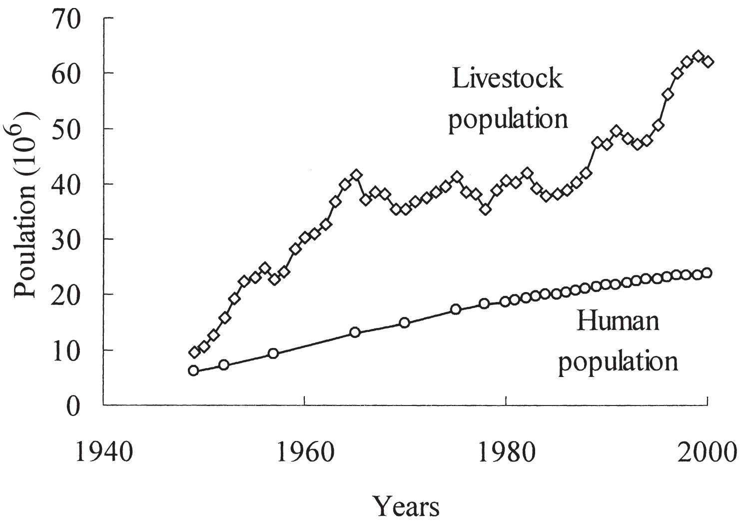

Figure 4. Evolution of the human and livestock population in Inner Mongolia from 1949 to 2000 (Source: Inner Mongolia Autonomous Region Bureau of Statistics, People's Republic of China, 2001).

resources can be expected with a rapidly incresing population living on the land in north China. Increasing population pressures plus the need for economic development result in intensified human activities, such as overgrazing, over-cultivation, excessive firewood gathering, irrational use of water resources and environmental neglect from industrial mining. All of these factors contribute to desertification in northern China (Zhu, 1998). For example, in Inner Mongolia the population is now nearly four-times that of 50 years ago and the livestock population has increased from 10 million, 50 years ago, to 60 million today. The region experienced two periods with a rise in livestock population, 1950–1965 and 1985–2000 (Figure 4). The livestock population densities of grazing animals were far beyond the carrying capacity on many of the rangelands of north China, resulting in poor grassland in these areas (Sheehy, 1992). Animal populations on rangelands in arid and semiarid areas have exceeded carrying capacity by 30–70 per cent (Liu *et al.*, 2002). Overgrazing may lead to a progressive reduction in the vegetation cover and increased wind erosion and runoff, which are conducive to desertification (Le Houérou, 1977). Another consequence of overgrazing is the destruction of native forage plants, which are then replaced either by annuals having little forage value or by unpalatable and toxic species (Milton *et al.*, 1994). For example, *Cynanchum komarovii*, a toxic annual, was associated with the rangeland subjected to heavy grazing in the Mu Us Sandy Land, north-central China.

The expansion of the cultivated areas experienced two climaxes in 1950–1960 and 1990–2000 (Figure 5). Cropping practices in arid and semiarid areas usually expose bare soils to wind erosion much of the year and soils lose productivity and are left barren after several years' cropping (Li and Wang, 1988). Cultivation can accelerate the wind-erosion rate of fixed aeolian sandy soil by several hundreds of times that of undisturbed soil (Li *et al.*, 2004). Firewood gathering is severe in locales short of energy. Natural vegetation provides more than 50 per cent of everyday fuel demand in the Mu Us Sandy Land (Ci and Liu, 2000). In some regions, local people have not run out of firewood that was collected 20 years ago!

Besides the increase in human and animal populations, other causes of human-induced desertification are irrational land-use practices and exploitation of natural resources. Unsound land-development policy, 'putting grains in command', led to large-scale land clearing for cultivation before 1980 and resulted in rapid expansion of desert (Luk, 1983). After 1980, when Chinese economic reform was initiated, short-term economic returns were prioritized while disregarding environmental conservation and sustainability. Human economic activities aggravated the situation of water shortage in north China. The development of irrigated farmland and industrial mining increased consumption of surface water and exploitation of ground water. Within Inner Mongolia for

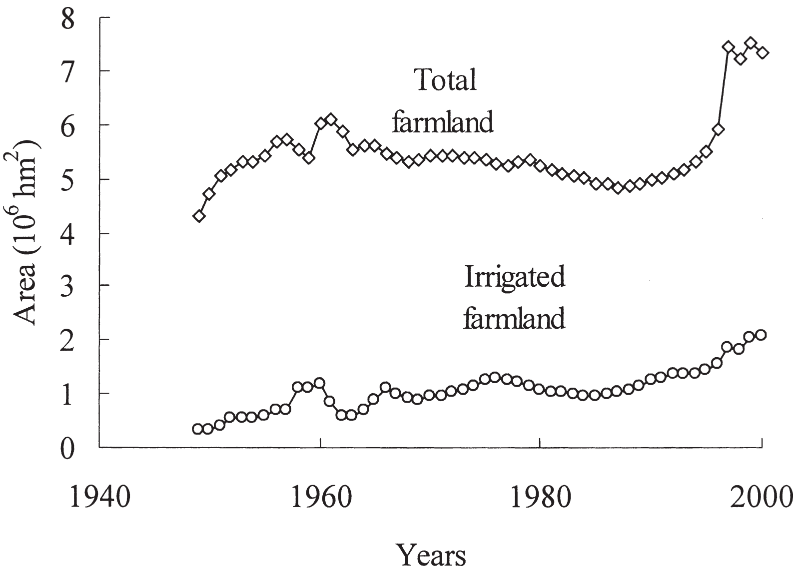

Figure 5. Variation of the area of the total farmland and irrigated farmland in Inner Mongolia from 1949 to 2000 (Source: Inner Mongolia Autonomous Region Bureau of Statistics, People's Republic of China, 2001).

example, irrigated farmland has increased from 0·35 million hm^2 50 years ago to 2·07 million hm^2 today, which has aggravated the water-shortage situation (Figure 5). Coal mined in Inner Mongolia climbed from 10·8 billion kg in 1980 to 51·6 billion kg in 1997 and although it declined a little, it remained as high as 45·1 billion kg in 2000, which put great demand on ground water (Figure 6).

Human disturbance to dry sandy soils can increase supplies of surface silt for transport (Tsoar and Pye, 1987). Vegetation is efficient at trapping dust. The erroneous methods of land use, such as reclaiming land from lakes and wild hills, deforestation and destruction of vegetation cover, causes land to lose dust traps and seed banks. There

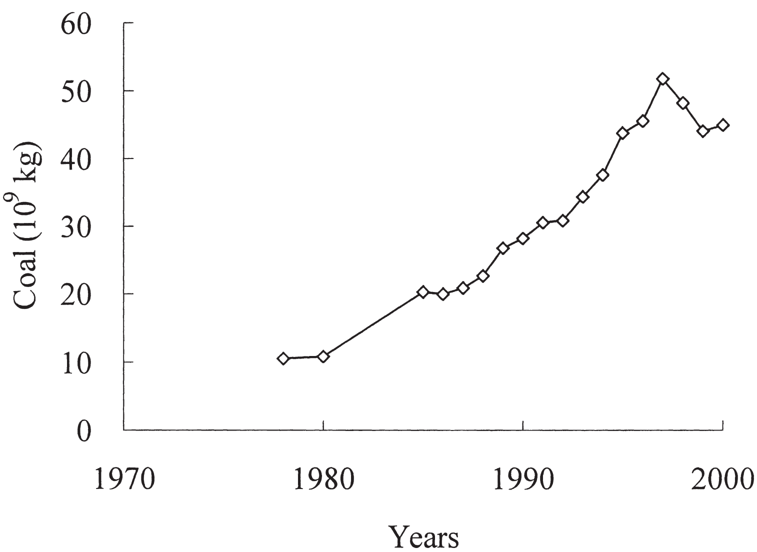

Figure 6. Coal production in Inner Mongolia from 1978 to 2000 (Source: Inner Mongolia Autonomous Region Bureau of Statistics, People's Republic of China, 2001).

are negative consequences from land degradation. The deterioration of vegetation will make the soil more susceptible to wind and water erosion that take the scarce soil organic matter and mineral nutrients away and in turn prevent vegetation recovery. As a result, desertification will proceed in steps, which are increasingly difficult and costly to reverse.

Although it is virtually impossible to separate anthropogenic impact from that of climatic change, as the two processes often work together, many research findings have suggested the dominant contributions of human activities to desertification in north China. Ding *et al.* (2001) and Zhou (2000) reported the evidence of human-induced desert expansion over historical time by examining the eolian grain size and sedimentation. Remarkable instances of human-induced desertification of semiarid steppe grassland have been documented dating back to the Han Dynasty (Zhu *et al.*, 1988; Sheehy, 1992). On contemporary desertification, Zhu *et al.* (1988) suggested that 94·5 per cent of desertification on sandy steppe or reactivated vegetated dunes was associated with human disturbance. Many research findings concluded that climate dominated desert forming through the geological ages while human activities have controlled desertification processes in recent decades (Dong *et al.*, 1998; Zhu, 1998). Much desertification actually occurred as a blistering processes on rangeland, which was climatically steppe and is now covered with mass mobile sand dunes. Among the human causes of desertification, reclamation of grassland was said to be the most important one (Enkhee and Erden, 2002; Aoren, 2003). The reclamation tide from the late-1950s to the 1960s caused about one hundred thousand km^2 of land desertification (Chen *et al.*, 1998). The natural vegetation is well adapted to its climate, and it is human interventions that make the land system more vulnerable to climatic variability (Nicholson *et al.*, 1998). This situation is very similar to the American Dust Bowl of the 1930s, which was due to agricultural devastation.

FAILURES IN COMBATING DESERTIFICATION

Although desertification-control efforts have been expanded since the mid-1950s, only minor successes were achieved, which resulted in the improvement of desertified land in just some local areas (Luk, 1983; Fan and Zhou, 2001; Runnström, 2003; Wang *et al.*, 2004). The cause can be traced to the fact that the desertification-control programme was not comprehensive, the conceived anti-desertification methods were groundless in most cases and success was unlikely. Efforts were focused on desertification control but not prevention. Specifically, failures in combating desertification primarily arose from the following aspects.

Little Scientific Involvement in Decision-making Dealing with Desertification

A dilemma exists because short-term objectives conflict with long-term goals. Scientific research needs a step-by-step development strategy and does not necessarily provide instant solutions to urgent problems. This means that we have to act before scientific consensus is achieved because of the urgency for desertification control in north China.

Scientific research on desertification has not been persistently undertaken in north China. The discontinuous and short-term research on desertification provided only a superficial knowledge of the problem and was a limited contribution to combating desertification. In addition, there was an unfavourable situation in that scientific findings were usually unheeded in the decision-making processes. The decision-making processes in most cases relied on subjective assumption rather than objective investigations into the involved areas or problems. The policies of mass reclamation and land abuse were implemented rashly, regardless of the biophysical properties of different areas. In fact, the fragility of the arid and semiarid ecosystems of north China had been realized by Chinese scientists for a long time, but this exerted little influence on the Government's policies on land management. In addition, control activities relied almost exclusively on planting trees and grasses, but this is not necessarily suitable in every location and time. No definitive, universal 'quick-fix' solution to desertification can be found given the diversity of the contributory factors (Thomas, 1997). Suitable solutions should vary with different places in terms of local physical and social conditions. In fact, the spread of desertified land continues despite the increasing percentage of forest cover (Ye and Hu, 2000). Science could play a vital role in addressing such issues as the functioning of dryland environmental systems and the determination of an ecologically realistic carrying capacity for the land.

Neglect of the Human Dimension of Desertification

Human attitudes and decision-making changes were crucial to finding a solution to desertification because of its socio-economic origin (Thomas, 1997). The rights and environmental knowledge of the local people who are directly afflicted by desertification were overlooked. The war against desertification will not be won unless the livelihood of local people is fully considered and they are convinced that their cooperation is essential and critical in combating the problem. For degraded land, withdrawal of farmlands and enclosing pastures in order to exclude grazing are undoubtedly the most effective ways to prevent further desertification. These measures would deprive local people of their sole livelihood. Worldwide, it was realized as early as 1970 that environment and development problems were inseparable and that it was futile to attempt to deal with environmental problems regardless of human demographic dynamics and social issues (Makhanya, 2004). Only when people's well-being is raised to a considerable level, can the vicious circle between poverty and environment be reversed and sustainable development be expected.

Institutional arrangements in force for dealing with desertification ignored the human element (Zhang and Zhang, 2001). The Chinese Government fought against the desertification in isolation from the land-user. There was, and is, no effective incentive scheme encouraging farmers and herdsmen to restore the degraded land. Tenure of land use by individual families was too short to encourage the prevention of desertification. The goal of government to arrest desertification can't be achieved unless it matches the relevant people's wills and actions. A great need exists for institutional involvement in desertification control in China.

Lack of a Well-organized Desertification-monitoring System

Long-term studies are needed to identify land-degradation processes (Rasmussen *et al.*, 2001). A well-organized longitudinal desertification-monitoring system can give a spectrum of historical land changes, which will help to recognize where and how desertification occurs so that timely measures can be taken to prevent escalating environmental degradation of the land. It is also necessary to judge whether desertification-control measures are effective. Monitoring anti-desertification methods is important to informative decision-making. It can be achieved by the '3 S' techniques including remote sensing, geographical information systems, and global positioning systems, together with field investigations. The available field data about desertification nowadays came from several field research stations of the Chinese Academy of Sciences, such as Shapotou Experimental Station, Naiman Field Station, Ordos Sandland Ecological Station, but that is far from enough for us to grasp the national and regional situations of desertification. A hierarchical monitoring network at national, regional and local scales, together with systematic studies on desertification processes is essential for sound land-use and management decision-making.

CONCLUSIONS

Although it is hard quantitatively to distinguish human contributions from natural contributions to desertification, it can be concluded that both are indispensable considerations regarding current desertification in north China. Dominant factors causing desertification vary with different areas and periods. The harsh abiotic conditions in north China, such as climate, sandy soils and water shortage, provide a desertification background. The climatic aridity occurring in recent decades in north China added further stress to the land. Human activities and mismanagements provided a pervasive catalyst for land degradation, and many research findings have supported the point of view that humans play a leading role in contemporary desertification in north China.

Failures in desertification control promoted ever more severe desertification. The desertification-control programme was ineffective because it was not comprehensive and positive results were limited to only a few places. Primary programme deficiencies included little scientific involvement in decision-making, neglect of the human dimension and the lack of a well-organized desertification monitoring system.

The national programme to promote agricultural production rather than desertification control must be revised before eco-environment improvement can take place. Because population pressure on land cannot be expected to decrease in the near future, how to reconcile the livelihoods of local people with land sustainability is the key to desertification control. A comprehensive programme that seriously includes the human dimension and scientific involvement and is based on a well-organized desertification-monitoring system may provide hope for the future of north China.

ACKNOWLEDGEMENTS

We thank Professor Paul B. Frederic and Elizabeth A. Frederic of the University of Maine at Farmington for their valuable editing and suggestions. We are greatly indebted to the anonymous referee for his/her valuable comments on our manuscript. We also wish to thank Professor You Lianyuan of the Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences for his provision of some relevant data. This research was supported by a grant from the National Natural Science Foundation of China (Grant to Chen Yufu, No. 40201006) and the Knowledge Innovation Project of the Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences (Grant No. CXIOG-A04-04).

REFERENCES

Aoren Q. 2003. Changes and innovations of the property right system of grassland. *Inner Mongolia Social Sciences* **24**: 116–120.

Chen J, Mu X. 2000. Tendency, causes and control measures on Yellow River dry-up. *Journal of Natural Resources* **15**: 31–35.

Chen L, Zhu W, Wang W, Zhou X, Li W. 1998. Studies on climate change in China in recent 45 years. *Acta Meteorologica Sinica* **56**: 257–271.

Ci L. 1994. The impact of global change on desertification in China. *Journal of Natural Resources* **9**: 289–303.

Ci L, Liu Y. 2000. Driving action of population increase on desertification. *Journal of Arid Land Resources and Environment* **14**: 28–33.

Ding ZL, Yu ZW, Yang SL, Sun JM, Xiong SF, Liu TS. 2001. Ceoval changes in grain size and sedimentation rate of eolian loess, the Chinese Loess Plateau. *Geophysical Research Letters* **28**: 2097–2100.

Domrös M, Peng G. 1988. *The Climate of China.* Springer-Verlag: Berlin.

Dong G, Jin H, Chen H, Zhang C. 1998. Geneses of desertification in semiarid and subhumid regions of northern China. *Quaternary Sciences* **18**: 143–153.

Enkhee J, Erden B. 2002. A summary of the China–Japan symposium on grassland desertification in Inner Mongolia and its countermeasures. *Journal of Inner Mongolia University (Humanities and Social Sciences)* **34**: 113–116.

Fan S, Zhou L. 2001. Desertification control in China: possible solutions. *Ambio* **30**: 384–385.

Fullen MA, Mitchell DJ. 1994. Desertification and reclamation in north-central China. *Ambio* **23**: 131–135.

Gray LC. 1999. Is land being degraded? A multi-scale examination of physical measurement and social explanations from western Burkina Faso. *Land Degradation & Development* **10**: 329–343.

He F, Wang G. 2001. The impact of river seasonalization on ground water and environmental in Haihe drainage basin. *Progress in Geography* **20**: 286–295.

Inner Mongolia Autonomous Region Bureau of Statistics, People's Republic of China. 2001. *Inner Mongolia Statistical Yearbook 2001*. China Statistics Press: Beijing.

Le Houérou HN. 1977. The nature and causes of desertization. In *Desertification: Environmental Degradation in and Around Arid Lands*, Glantz MH (ed.). Westview Press: Boulders, Co; 17–38.

Le Houérou HN. 1996. Climate change, drought and desertification. *Journal of Arid Environments* **34**: 133–185.

Li J. 2001. Temporal variation of droughts in northern parts of China. *Agricultural Research in the Arid Areas* **19**: 42–51.

Li S, Wang S. 1988. On the climatic boundary of agro-pastoral zone in the semiarid areas of north China. In *Research on the Natural Resources of the Arid and Semiarid Areas in China*, Anon (ed.). Natural Resources Research Society of China, Science Press: Beijing; 108–124.

Li X, Tang Q, Fu S. 1993. *Research on Low Flows of Rivers of China*. Ocean Press: Beijing.

Liu X, Liu L, Wang J. 2004. Wind tunnel simulation of aeolian sandy soil erodibility under human disturbance. *Geomorphology* **59**: 3–11.

Liu L, Zhang F, Zhao Y. 2002. A predicting analysis of comprehensive productivity of China's rangeland resources from 2000 to 2050. *Acta Prataculturae Sinica* **11**: 76–83.

Luk SH. 1983. Recent trends of desertification in the Maowusu Desert, China. *Environmental Conservation* **10**: 213–224.

Makhanya EM. 2004. Demographic dynamics and land degradation at Ratau, Lesotho, in the context of rural sustainability. *Land Degradation & Development* **15**: 257–269.

Milton SJ, Dean WRJ, du Plessis MA, Siegfried WR. 1994. A conceptual model of arid rangeland degradation. *BioScience* **44**: 70–76.

Mitchell DJ, Fullen MA, Trueman IC, Fearnehough W. 1998. Sustainability of reclaimed desertified land in Ningxia, China. *Journal of Arid Environments* **39**: 239–251.

Nanking Institute of Soil Science, Academia Sinica. 1980. *Soils of China*. Science Press: Beijing.

Nicholson SE, Tucker CJ, Ba MB. 1998. Desertification, drought, and surface vegetation: an example from the west African Sahel. *Bulletin of the American Meteorological Society* **79**: 815–829.
Qin B. 1999. A preliminary investigation of lake evolution in 20-century in inland mainland Asia with relation to the global warming. *Journal of Lake Sciences* **11**: 11–19.
Rasmussen K, Fog B, Madsen JE. 2001. Desertification in reverse? Observations from northern Burkina Faso. *Global Environmental Change* **11**: 271–282.
Ren L, Wang M, Li C, Zhang W. 2002. Impacts of human activity on river runoff in the northern area of China. *Journal of Hydrology* **261**: 204–217.
Runnström MC. 2003. Rangeland development of the Mu Us Sandy Land in semiarid China: an analysis using Landsat and NOAA remote sensing data. *Land Degradation & Development* **14**: 189–202.
Shang K, Dong G, Wang S, Yang D. 2001. Response of climatic change in north China deserted region to the warming of the Earth. *Journal of Desert Research* **21**: 387–392.
Sheehy DP. 1992. A perspective on desertification of grazingland ecosystems in north China. *Ambio* **XXI**: 303–307.
Shen Y, Wang J, Wu G, Han D. 2001. *Oasis of China*. Henan University Press: Kaifeng.
Strahler AN, Strahler AH. 1983. *Modern Physical Geography*, 2nd edn. Wiley: NY.
Thomas DG. 1997. Science and the desertification debate. *Journal of Arid Environments* **37**: 599–608.
Tsoar H, Pye K. 1987. Dust transport and the question of desert loess formation. *Sedimentology* **34**: 139–153.
Walker AS. 1982. Deserts of China. *American Scientists* **70**: 366–376.
Wallace A. 1994. Environmental destruction called desertification. *Communications in Soil Science and Plant Analysis* **25**: 101–104.
Wang T, Li XZ, Li QS. 1991. A preliminary study of present land desertification in Bashang Plateau, Hebei Province. *Journal of Desert Research* **11**: 39–45.
Wang T, Wu W, Xue X, Sun QW, Zhang WM, Han ZW. 2004. Spatial-temporal changes of sandy desertified land during last 5 decades in northern China. *Acta Geographica Sinica* **59**: 203–212.
Wang X. 1999. Water resource and environmental protection of energy base in Er Duosi plateau. *Inner Mongolian Environmental Conservation* **11**: 15–18.
Warren A. 2002. Land degradation is contextual. *Land Degradation & Development* **13**: 449–459.
Wu B, Ci L. 2002. Landscape change and desertification development in the Mu Us Sandland, Northern China. *Journal of Arid Environments* **50**: 429–444.
Wu W, Wang XZ, Yao FF. 1997. Applying remote-sensing data to desertification monitoring in the Mu Us Sandy Land. *Journal of Desert Research* **17**: 415–420.
Wulan T. 2002. The development of agriculture and changes of land use in Horqin in the 20th century. *Journal of Natural Resources* **17**: 157–161.
Xu J. 2004. A study of anthropogenic seasonal rivers in China. *Catena* **55**: 17–32.
Ye D, Chen P. 1992. *A Primary Study on Global Change in China*. Earthquake Press: Beijing.
Ye D, Chou J, Liu J, Zhang Z, Wang Y, Zhou Z, Ju H, Huang Q. 2000. Causes of sand-stormy weather in northern China and control measures. *Acta Geographica Sinica* **55**: 513–521.
Ye M, Hu W. 2000. Thinking on the desertification problem of west China. *Disaster Reduction in China* **10**: 23–27.
Zha Y, Gao J. 1997. Characteristics of desertification and its rehabilitation in China. *Journal of Arid Environments* **37**: 419–432.
Zhang B, Zhang R. 2001. Analysis of institutional arrangement in sandy desertification areas of China. *China Population, Resources and Environment* **11**: 94–97.
Zhong DC. 1998. *Dynamic Evolution of Sand Desert in China.* Gansu Culture Press: Lanzhou.
Zhou WJ. 2000. Environmental variability within the Chinese desert-loess transition zone over the last 20 000 years. *Holocene* **12**: 117–122.
Zhu Y, Wu W, Drake S. 2004. A survey: obstacles and strategies for the development of ground-water resources in arid inland river basins of Western China. *Journal of Arid Environments* **59**: 351–367.
Zhu Z. 1989. Advances in desertification research in China. *Journal of Desert Research* **9**: 1–13.
Zhu Z. 1998. Concept, cause and control of desertification in China. *Quaternary Sciences* **18**: 145–155.
Zhu Z, Chen G. 1994. *Sandy Desertification in China*. Science Press: Beijing.
Zhu Z, Liu S, Wu Z, Di X. 1986. *Deserts in China*. Science Press: Beijing.
Zhu Z, Liu S, Di X. 1988. *Desertification and Rehabilitation in China*. The International Centre for Education and Research on Desertification Control: Lanzhou.

