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Wind Erosion in Arid and Semiarid China: An Overview*

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摘 要: 土壤风蚀是中国干旱、半干旱地区的主要环境问题之一。综合近年来有关我国不同地区土壤风蚀风洞模拟实验与野外研究成果,根据风蚀气候指数和沙尘暴日数的分布,指出了我国的风蚀区域与沙尘暴活动中心。

关键词: 中国; 干旱半干旱地区; 土壤风蚀

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1 Introduction

The vast expanse of arid and semiarid lands in China has been experiencing very severe erosion by wind[1]. Dry sub-humid lands are also frequently threatened by wind erosion when strong winds coincide with dry periods. According to the method suggested by Thornthwaite[2], Ci and Wu[3] estimated that China's arid and semi-arid land (including hyper-arid and dry sub-humid) is about 3.57 million km^2. All experience wind erosion and almost 60% have already been degraded[4]. Evidences show that wind erosion in China is not a recent phenomenon. The landscapes sculptured by wind, such as yardags and deflated gobi deserts, are distributed extensively in Northwest China[5]. The extensive aeolian deposits of different geological eras bear rich information on the aeolian processes in the geological past[6]. The rapidly expanding wind eroded land in the last five decades, and the increasing frequency of dust storms imply that the current wind erosion is accelerating at an unprecedented rate.

Documentation of wind erosion and its related dust storms in China dates back to over 2 000 years. "Earthy rain" and "Sandy rain" recorded in history were actually the rain-laden dust resulting from wind erosion[7,8]. The historically famous geographer in Wei Dynasty, Li Daoyuan made such explanations to the formation of Yardags, "Rills cut by water is blown by wind subsequently."[9]. Some local administrators in Qing Dynasty organized the local people to take practical measures to protect farmlands and irrigation canals from blown sand. After a few years (1866—1872) investigation in the Loess Plateau of China, Richthoffen attributed the thick loess deposition to the wind erosion of the sandy deserts and gobi deserts to the northwest[1]. At the turn of this century, Hedin noted that the yardags nearby Lop Nor was eroded 6 m deep by wind in 1 600 years. The estimated annual wind erosion rate was 4 mm · a^{-1}, or 6 000 t · km^{-2} · a^{-1}[1]. The drought in the north of China in the 1930's of this century led to the extensive destruction of vegetation cover and expansion of wind erosion. Scientists began to recognize the wind erosion problems in this area. Since China's reunification, the rapid increase of population led to large-scale land reclamation and deforestation in the semi-arid zone, which resulted in loosened soil free of cover subjected to wind action. No systematic research work concerned with wind erosion has been conducted in China except those laboratory tests and field observations with respect to the

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sand stabilization in desert areas to ensure the urgent resource development and other economic activities. Recent years there are the increasing interest in wind erosion research on rain-fed farmlands in northern China. Attempts have been made to learn the general situations, mechanics, causes and control techniques of wind erosion by laboratory wind tunnel simulation and field observation in some typical areas. Some encouraging preliminary results have been obtained.

2 Climatic erosivity

The influence of climate on wind erosion depends not only on wind velocity, but also on precipitation and temperature that determines evaporation. The pioneer wind erosion scientists, Chepil *et al*[12] developed a formula to calculate a wind erosion climatic factor for the Wind Erosion Equation (WEQ)[13]. Later, Skidmore[14] introduced the concept of probability function of wind speed and put forth another formula for calculating wind erosion climatic factor to increase the accuracy of estimation. Owing to the limited availability of detailed meteorological data, Dong *et al.* [15] employed the formula proposed by FAO[16] that proved to produce very close results to Skidmore's method. The FAO method can be expressed as:

$$C = (1/100)\sum_{i=1}^{12} u^3((ETP_i - P_i)/ETP_i)d \quad (1)$$

where, C = Wind erosion climatic factor; u = Mean monthly wind speed at 2 m height; ETP_i = Potential monthly evaporation amount (mm); P_i = Monthly precipitation (mm); d = The number of days in the month concerned.

The yearly wind erosion climatic factor in arid and semiarid China ranges from 10 to 150 based on the meteorological data from 233 stations covering sections of 12 provinces in northern China. Wind erosion mainly occurs to the north of Yellow River in the eastern part, north of Qinling Mountain in the middle part, and north of Tibetan Plateau in the western part. In the east, the climatic factor increases from southeast to northwest, while in the west, it increases from west to east. There exist obvious regional differences in climatic factor. Six wind erosion centers can be discerned, which are Junggar Basin, Qaidam Basin, Alashan Gobi, northern Inner Mogolia Plateau, Horqin Steppe and Taklimakan Desert. The wind erosion climatic factor is also changeable with season. Spring has the greatest climatic factor due to strong wind and little precipitation. Summer has the least climatic factor. The direction of wind erosion force also shows regional difference. To the east of longitude 97°E, west of longitude 84°E of Tarim Basin and Junggar Basin NW is the prevailing direction. To the west of longitude 97°E, eastern Xinjiang and east of longitude 84°E of Tarim Basin NE wind is predominant. The seasonal distribution and direction of wind erosion force imply that the major weather system responsible for the wind erosion in arid and semi-arid China is the Mogolia high-pressure that is very active in the spring.

3 Surface erodibility

The mechanical composition, structure and the bonding agents between particles determine the erodibility of the ground surface, but the effect of bonding agents is complex. In arid and semi-arid areas of China, wind erosion usually occurs on loose deposits or those loosened by natural or human factors. So the surface erodibility can be approximately assessed by mechanical composition (Tab. 1). The particles smaller than 0.25 mm and larger than 0.08 mm are the most easily eroded. The ground materials subjected to wind erosion in the arid and semiarid areas of China can be divided into such seven primary types that include gobi desert, sandy desert, loess deposits, residuum, flooding deposits, salinized deposits and irrigation deposits.

Tab. 1 The grain size composition of typical ground surface material subjected to wind erosion in the arid and semi-arid areas of China

Type	Gravels	2～1.0 mm	1～0.5 mm	0.5～0.25 mm	0.25～0.125 mm	0.125～0.063 mm	<0.063 mm
Gobi desert	23.2	7.07	8.50	9.64	11.84	19.57	20.18
Sandy desert	0	0	1.08	3.57	48.44	45.87	0.96
Loess deposits	0	0	0	0.73	0.90	22.13	76.24
Residual deposits	2.83	1.43	2.43	9.19	31.93	33.76	18.43
Flooding deposits	0	0	0.60	0.90	32.41	44.31	21.78

Gobi desert, distributed in northern Mogolia Plateau, Hexi Corridor of Gansu Provinces, eastern Xinjiang Autonomous Region, Qaidam Basin of Qinghai Province, northern Junggar Basin of Xinjiang and the surrounding edge of Taklimakan Desert, is the lag gravel of long term deflation. Hardly any erosion occurs on the original gobi deflation plane except when disturbed. Sandy deserts, scattered in different parts, are the most easily eroded by wind because more than 80% of the sand grains is within range between 0.08 and 0.25 mm in size. Loess deposits, the main body of the Loess Plateau, are in fact the fine particles emitted and transported by wind from the gobi deserts and sandy deserts to its northwest. The grain size of loess deposits decreases gradually from the northwest to southwest. Due to the rich physical clay and bounding agents loess deposits usually are less erodible except in the northwestern part adjacent to sandy desert. The majority of the residual deposits, distributed in the east and southeast of Inner Mogolia Plateau, are the deposits left behind by both water and wind erosion. They are also less erodible because of the considerable amount of non-erodible fraction. The flooding deposits are distributed to the north of Yellow River of the North China Plain. In general, they are less erodible due to considerable amount of physical clay and the bonding agents, but those along the abandoned river channels are easily eroded because they are coarser and in most cases at loose state. Irrigation deposits are scattered on the terraces of the Yellow River valley. The irrigation deposits are the very fine sedimentation covering irrigated farmlands deposited from turbid irrigation water through long term of irrigation. Because over 90% of the particles are smaller than 0.05 mm and in most cases at moistened state irrigation deposits are almost non-erodible. Salinized deposits are the deposits with very high content of salt and alkaline. Larger and continuous patches of salinized deposits are distributed on the northern bank of Tarim River to the north of Taklimakan Desert and at the foot of Tianshan Mountain. Due to the protection afforded by the salt crust, the salinized deposits are rarely eroded by wind.

4 Wind erosion intensity

The estimate of wind erosion intensity is important for the design of control measures, but it is also a difficult task due to the difficulty in methodology. Attempts have been made in recent years to determine the wind erosion intensity in the arid and semi-arid areas of China. Methods include investigation of some obvious wind erosion signs, such as the exposure height of tree roots, the height of wind eroded landforms, the base exposure height of buildings; field observation by means of erosion pins[17], erosion bridges[18] and sand samplers; monitoring survey of the landform change; simulative experiment in wind tunnel[19]; analyzing the grain size distribution of the wind eroded soil and comparing it with the original state without erosion[20]; estimate by Wind Erosion Equation[17]. Very recently some researchers tried to apply ^{137}Cs trace element method[21,22]. Tab. 2 summarizes the estimated wind erosion rate in some typical sample areas. The estimated wind erosion rate in the arid and semi-arid of China ranges between 600～8 000

$t \cdot km^{-2} \cdot a^{-1}$, or 0.4～5.3 $mm \cdot a^{-1}$ and the most severe erosion takes places in active dune-field. Farmland have higher wind erosion rate.

Tab. 2 The wind erosion intensity of some typical areas

Location	Climatic type	Land type	$E/(t \cdot km^{-2} \cdot a^{-1})$	$h/(mm \cdot a^{-1})$
Naiman Inner Mogolia[18]	Dry sub-humid	Sandy land	8 000	5.33
Yufa, Beijing[17]	Dry sub-humid	Farmland	1 330	0.89
Xiajing, Shandong[23]	Dry sub-humid	Sandy land	2 100	1.40
Youyu, Shanxi[24]	Dry sub-humid	Loess farmland	1 373	0.92
Shenmu, Shaanxi[25]	Dry sub-humid	Loess farmland	1 900	1.27
Bagudi, Inner Mogolia[20]	Semi-arid	Farmland	4 110	2.74
Xijingzi, Inner Mogolia[20]	Semi arid	Farmland	2 460	1.64
Banweizi, Inner Mogolia[20]	Semi-arid	Farmland	3 105	2.07
Qihao, Inner Mogolia[20]	Semi-arid	Farmland	1 905	1.27
Dagaitan, Inner Mogolia[20]	Semi-arid	Farmland	1 440	0.96
Yongxian, Inner Mogolia[20]	Semi-arid	Farmland	2 880	1.92
Gonghe, Qinghai[22]	Semi arid	Farmland	2 236	1.49
Gonghe, Qinghai[22]	Semi arid	Active dunefield	4 368	2.91
Gonghe, Qinghai[22]	Semi-arid	Grassland	744	0.50
Lop Nor, Xinjiang[12]*	Arid	Sandy desert	6 000	4.00
Kuerle, Xinjiang[21]	Arid	Farmland	3 537	2.36
Kuerle, Xinjiang[21]	Arid	Desertified farmland	5 987	3.99
Kuerle, Xinjiang[21]	Arid	Grassland	3 171	2.47

* Because the Lop Nor area is free of human disturbance, the wind erosion rate is assumed to be a constant. E is wind erosion modulus, h is wind erosion depth, the bulk density is taken to be $1.5\ t \cdot m^{-3}$.

5 Anthropogenically-accelerated wind erosion

The north of China, especially the semi-arid zone has a fragile ecological system that is sensitive to human disturbance. This area was covered by grasses, herbs, shrubs and trees. As population increased more and more people moved to northern China. Consequently, the original vegetation cover was destroyed by over-reclamation for farming, over-grazing, irrational cutting for firewood and misuse of water resources[26]. As more and more bare and loose surface is exposed by human activities wind erosion is accelerated. The comparative simulative wind tunnel experiment of cultivated and non-cultivated soil shows that wind erosion may be accelerated 15 times by cultivation. Animal-treaded soil has 14.4% more wind erosion than non-treaded[27].

The anthropogenically-accelerated erosion can be indicated by the difference in wind erosion rate between farmland and grassland. For economic reasons the farmland in the arid and semi-arid of China is usually cleared of any residues at post-harvest season. Yan[22] concluded that in Gonghe Basin of Qinghai Province the annual wind erosion rate of farmland is three times greater than the grassland. During cultivation wind erosion may increase 5.74 ～ 8.80 times. Dong and Chen[20] reached similar conclusion for Houshan Area of Inner Mogolia. The land reclamation in Houshan Area began at the turn of this century, large-scale reclamation occurred after the 1950's. This leads to the wind erosion difference between farmland and grassland (Tab. 3). The accumulated wind erosion depth on farmland usually is over 10 cm, while that in the grassland is no more than 5 cm. Field investigation indicates that most of the wind-eroded landforms, such as yardags, appeared after the 1960's[20], in accordance with the rapid increase of population and large-scale land reclamation. The local people use the term "Clear wind" and "Yellow wind" to describe the local environment before and after the 1960's[20]. This is a good evidence to the environmental degradation caused by wind erosion. Beijing, China's capital city is experiencing more and more dust storms and dust-fall. Some researchers consider Houshan Area of Inner Mogolia is the primary source of the dust over Beijing[28].

Tab. 3 Comparison of the accumulated wind erosion amount between cultivated land and grassland in Houshan area, Inner Mogolia[33]

Location	Type of land use	Wind erosion depth/cm
Zhanggaiyingzi	Flat farmland	12.58
Banweizi	Slope farmland	14.86
Yongxian	Flat farmland	14.12
Qihao	Farmland on the top of hill	10.87
Bagudi	Slope farmland	18.70
Xijingzi	Farmland on the top of hill	12.71
Erdaohe	Grassland	4.84
Dagaitan	Grassland	4.65

6 Dust storms

Dust storms in the arid and semi-arid areas of China have very long history. The earliest recorded dust storm dated back to 205 B.C.[30]. The people in the arid and semi-arid areas suffered heavy loss in lives and properties due to dust storms. For example, the dust storm of May 18 to 19, 1986 in Hotian, Xingjiang resulted in on-site economic loss of 6 million dollars and the extensive dust storm of May 5, 1993, in Northwest China resulted in on-site economic loss of 70 million dollars[31].

There are five dust storm centers in the arid and semi-arid areas of China. They are, from west to east, Tarim Basin (mainly including Taklimakan Desert and Lop Nor area), Alashan Plateau (including Badain Jaran Desert, Tengger Desert, Ulan Buh Desert and Hexi Corridor), Ordos Plateau (including Mu Us Sandy Land and northern Loess Plateau), southeastern Inner Mogolia Plateau (including Houshan Area, Otindag Sandy Land and Horqin Sandy Land) and North China Plain (to the south of Beijing). According to the documented dust storms since 205 B.C. over 85% Dust storms occurred in March to May. The frequency and intensity of dust storms are increasing with population, which is mainly related to the adverse human disturbance against the background of climatic fluctuations. Since the reunification of China (1950—1995), the average frequency of dust storms is 1.73 times · a^{-1}.

7 The control of wind erosion

Since the reunification of China, the Chinese Government noted the necessity of controlling wind erosion to ensure economic development. Measures to be taken include vegetative, engineering and chemical methods and land management practices.

Vegetative measures include the construction of the shelter forest in the Three Norths (Northeast, North and Northwest China), which have lasted for two decades, the shelter belts or networks to protect the oasis. Air-seeding was successfully used to generate the grasses and shrubs to stabilize shifting sand dunes in the semi-arid areas. In desert areas where the natural conditions are not suitable for any vegetative measures, engineering methods are introduced. The engineering measures, mainly used to protect the transportation lines crossing desert, have been successfully practiced in the Shapotou Section of Bao (Baotou)—Lan (Lanzhou) Railway, Naiman Section of Jing (Beijing)—Tong (Tongliao) Railway, Yumen Section of Lan (Lanzhou)—Xing (Urumqi) and the Desert Highway in Taklimakan Desert. To now the engineering methods used in China include fences, straw checker boards, sand-transporting boards, feather-like sand-conducting fence arrays and sand-separating ditches. The purpose of chemical treatment to the loose shifting sand is to add bonding agents and form non-erodible crusting. Because of their prohibitive cost sand-fixing chemicals was only limited to small areas. Research is being conducted to reduce the cost. Land management practices, which were used on farmlands, include striped and alternated cultivation, residue-leaving harvest, deep tillage and zero tillage. But in most areas, the importance of land management in controlling wind erosion is ignored except for Gonghe Basin of Qinghai Province, a rare good example of preventing the development of wind erosion by properly managing the land.

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