Polish J. of Environ. Stud. Vol. 19, No. 2 (2010), 309-314

Original Research

Temporal-Spatial Distribution of Sand Storms in the Xilin Gol Area of Inner Mongolia

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Received: 26 February 2009
Accepted: 8 August 2009

Abstract

The Xilin Gol area is located in central Inner Mongolia, China. It had been a fertile prairie in northern China, but desertification and sand storms have increased in past decades. This study shows the spatial and temporal distribution of sand storms in the Xilin Gol area. The results of the analysis show:

(i) Factors such as strong winds (usually beyond seven levels), rain and temperature have an impact on sand storms. The correlation coefficient between sand storm days and strong wind days is 0.89.

(ii) There are more sand storm days in the west than in the east.

(iii) In the last 30 years, the frequency of sand storms have been consistently decreasing.

Keywords: temporal and spatial distribution, sand storm, Xilin Gol area, meteorology, desertification

Introduction

A sand storm is a weather phenomenon in which the ground dust or sand is blown by strong winds, which causes particulate-filled air that reduces horizontal visibility to less than 1 km. Such storms are an important natural disaster [1-3], and are a sign of the desertification of the land [4-12]. The frequency of sand storms is an important indicator of the degree of desertification. For example, there are four areas in the world where sand storms occur continually: Central Asia [13], North America, Central Africa and Australia. These are all significant areas of desertification. There are reasons why the northwestern region of China is prone to sand storms. There are three factors that give rise to sand storms: first, massive amounts of sand dust and soil particles are thrust into the air by strong winds; second, the soil texture must be dry and loose, the vegetation sparse, and the surface exposed; and third, the sand is transported to the air under certain conditions of strong convection weather. With the former two factors, it is easy for local sand storms to form, but if the three factors occur synchronously, a wide ranging sand storm will arise.

The sources, spatial distribution, frequency and trend of dust storms in China have been discussed. The characteristics of sand storms in China were analyzed in 2002, which show that the number of sand storms is 12, and that sand storm formation is strongest on 18~22 March. Sand storm days are greatest in the Hun Shandake desert in northern China. Spring is the season with the most sand storms. Research about temporal-spatial distribution of sand storms in the Xilin Gol area is limited. This article describes the relation between climatic factors and sand storms, and examines the temporal-spatial distribution of sand storms in the Xilin Gol Area.

Date and Methodology of the Study

The Xilin Gol area is located in central Inner Mongolia. It is an important product-base for livestock, and is also the front of western development in China. The Xilin Gol area

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Table 1. Correlation coefficients between the monthly number of sand storm days and related meteorological elements at select stations.

stations / climatic factors	ABa Ga	TaiPuSi	Duo Lun	Lan qi	Bai Qi	Xi Wu Qi	Huang qi	ZhuRi he	Su You qi	Su Zuo qi	Na Ren	Er Lian Hot	Dong Wu Qi	Wu Lagai	Xi lin Hot
Strong Wind Days	0.91*	0.91*	0.84*	0.84*	0.95*	0.90*	0.89*	0.85*	0.92*	0.80*	0.80*	0.88*	0.97*	0.93*	0.94*
Average Wind Velocity	0.88*	0.68*	0.70*	0.70*	0.91*	0.60*	0.82*	0.72*	0.82*	0.77*	0.77*	0.89*	0.93*	0.91*	0.96*
Ground Temperature	0.30	0.15	-0.01	-0.01	0.26	0.39	0.09	0.15	0.22	0.18	0.18	0.26	0.43	0.18	0.28
Relative Humidity	-0.8*	-0.39	-0.74*	-0.74*	-0.87*	-0.78*	-0.77*	-0.84*	-0.84*	-0.70*	-0.70*	-0.58*	-0.87*	-0.83*	-0.8*
Days of Snow	0.03	-0.06	-0.08	-0.08	-0.32	-0.35	-0.20	-0.27	-0.33	-0.30	-0.30	-0.37	-0.45	-0.22	-0.35
Evaporation	0.50	0.54	0.28	0.28	0.52	0.51	0.31	0.39	0.43	0.30	0.30	0.40	0.62*	0.46	0.49
Rainfall	-0.08	-0.29	-0.28	-0.28	-0.13	0.03	-0.28	-0.23	-0.17	-0.22	-0.22	-0.18	0.03	-0.17	-0.13
Average Temperature	0.28	0.12	-0.02	-0.02	0.23	0.31	0.04	0.11	0.19	0.15	0.15	0.23	0.40	0.15	0.25

* $p < 0.05$

is 115°13 '~117°06' E and 43°02' ~44°52'N. In the Xilin Gol area there are low mountains and hills in the southeast, and the terrain is flat in the northwest. The Hun Shandake desert is located in the Xilin Gol area too. In the Xilin Gol area, the annual mean temperature is between 0-3°C; the annual ice period is 5 months and the cold period is 7 months; the minimum temperature is -20°C in January, and the maximum temperature is 20°C in July. The average rainfall is 295 mm, and it decreases from the northwest to the southeast. Rainfall is mainly concentrated in July, August and September. Average snowfall is 8-15 mm. The annual average relative humidity is less than 60%. Evaporation is between 1,500-2,700 mm.

SAS computer software was used to compile the meteorological data, carry out the different classifications, and study the relationship between sand storms and climatic factors. Microsoft EXCEL was used to analyze the temporal distribution of sand storms, such as decadal variation, inter-annual variation and seasonal variation; and SURFER was used to describe the characteristics of storm spatial distribution.

The meteorological data originated from 15 meteorological stations in the Xilin Gol Area. It includes sand storm days, strong wind days, temperature, relative humidity, and so on. The temporal interval is from 1971 to 2000. All data are presented as annual and seasonal. Spring [14] is March to May, summer is June to August, autumn is September to November, and winter is December to February (the following year). Yearly mean value is used to report annual sand storm days, strong wind days, temperature and relative humidity. Monthly mean value is used to report seasonal sand storm days and strong wind days.

Data Analysis and Results

Influence of Climatic Factors

There is a close relationship between sand storms and climatic factors. This disastrous weather results from a confluence of certain climatic conditions [15]. The correlation between the monthly mean value of sand storm days and the related climatic factors can be shown (Table 1). The correlation coefficient between sand storm days and strong wind days is highest. This coefficient is 0.89 in the Xilin Gol Area, and is 0.97 in DONG Wuqi. There is a consistent correlation between sand storm days and average wind velocity and the mean correlation coefficient is 0.8. However, there is a close counter-correlation between sand storm days and relative humidity. The concrete analysis as follows shows:

1) it can be seen that the tendency of sand storm days and strong wind days in a year is basically consistent (Fig. 1). From March to September, there are more sand storm days when there are more strong wind days, because strong wind is a primary factor in creating sand storms. In spring, the earth is recovering [from the winter] and the land is loose, and with rising strong winds sand storms occur easily. However, from October to

February (in the next year), the tendency of sand storm days and strong wind days is inconsistent because the land surface is compact, and snow days are increasing, so although strong winds occur, it is difficult to generate sand storms.

2) Fig. 2 shows that the number of sand storm days increases in the spring, and at the same time the average wind velocity is increasing, too. In other words, average wind velocity is an important factor for producing sand storms. Fig. 3 shows that relative humidity is lowest and sand storms days are highest because of decreased rainfall in spring.

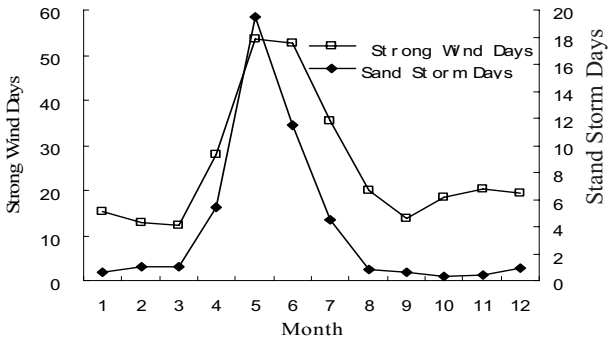

Fig. 1. Tendency of sand storm days and strong wind days in a year.

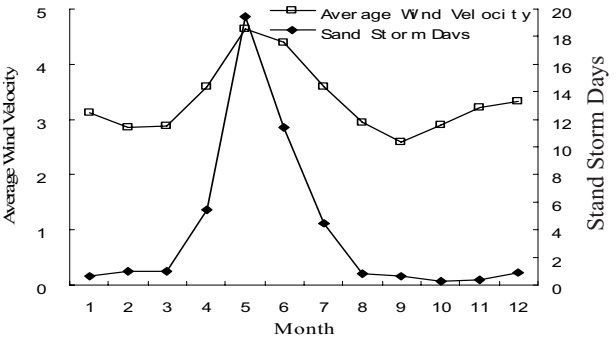

Fig. 2. Tendency of sand storm days and average wind velocity in a year.

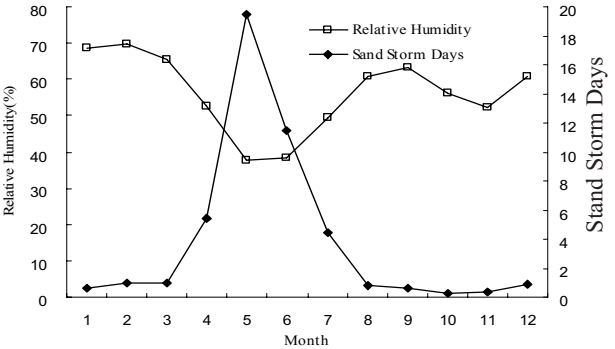

Fig. 3. Tendency of sand storm days and relative humidity in a year.

Table 2. Statistics of the decennary number of sand-dust storm of 15 meteorological stations in 30 years.

Stations	1970-1979	1980-1989	1990-1999
A Ba Gaqi	5.7	4	2.4
Tai Pu Siqi	8.2	4.7	0.5
Duo Lun	5.2	2	0.5
Zheng Lanqi	11.4	7.7	2.9
BAI Qi	7.4	6.2	2.4
Xilin Hot	6	1.9	0.2
Xi Wuqi	2.6	1.3	0.3
Huang Qi	5.2	3.9	3.8
Zhu Rihe	8.9	8.2	7.4
SU Youqi	17.1	8	4.1
SU Zuoqi	7.8	5.1	4.4
NA Ren	2	4.9	1.8
ER Lian	9.9	7.8	3.6
Dong Wuqi	3.8	2.8	1.3
WU Lagai	3	1.9	0.4
Average days	6.95	4.69	2.64

3) the change of surface temperature plays a role in seasonal change of sand storm. Surface temperature increased to over 0ºC at the end of February and decreased to lower than 0ºC in early November. The sand storm increased rapidly in March and April. When surface temperature decreased to lower than 0ºC, frozen soil and snow cover don't allow this phenomenon (sand storm) to form. However, thawing soil load to loose soil in spring, when the atmosphere is in an unstable state and wind speed is high, present ripe conditions for sand storm.

Temporal Distribution of Sand Storms

The frequency of sand storm formation shows a decreasing tendency from the 1970s to the 1990s (Table 2). In the 1970's the average number of sand storm days was 6.95, in contrast with the average number of sand storm days in the 1990's, which was 2.64 days – a 62% decrease. In the 1970's the maximum number of sand storm days was 17.1, in SU Zuoqi, and the minimum number of sand storm days was 2, in NA Ren. In the 1980's, in ZHU Rihe, the maximum number of sand storm days was 8.2 and the minimum number of sand storm days was 1.3, in XI Wuqi. In the 1990's the maximum number of sand storm days was 7.4 days, in ZHU Rihe, and the minimum number of sand storm days was 0.2, in XILIN Hot. Compared to other stations, analysis shows that decadal variation of sand storm is largest in XILIN Hot, and the amplitude of contraction of sand storm days is 97%.

According to research on sand storm rank and distribution characteristics in China, there is a classification standard concerning the frequency of sand storms as follows [16]. The region where the yearly number of sand storm days is 10 to 20 days is called a frequently occurring region; the region where the yearly number of sand storm days is 5 to 10 days is called an easy-happening area; the region where the yearly number of sand-dust storm days are less than 5 days is called an influence area. There are 6 meteorological stations located in an easy-happening area, and the frequency of sand-dust storms in SU Youqi is the strongest; there are 6 other meteorological stations located in an influence area, and the frequency of sand-dust storms in XI Wuqi is the lowest (Fig. 4). The widespread range of these storms indicate that it is high time we took some measures to protect the eco-environment, return farmland to forest, prevent over-grazing and prevent land desertification; only in this way can we reduce the frequency of sand storms.

Inter-annual Variation in the Xilin Gol Area is shown in Fig. 5. The number of sand storms overall show a declining trend in the 30 years from 1971 to 2000. This is particularly noticeable after 1976, when the number of sand storms is obviously reduced, though there are two obvious peaks: in 1984 and 1990. In all, the number of sand storms during this 30-year period has obviously declined. However, the related statistics indicate that the tendency of strong sand-

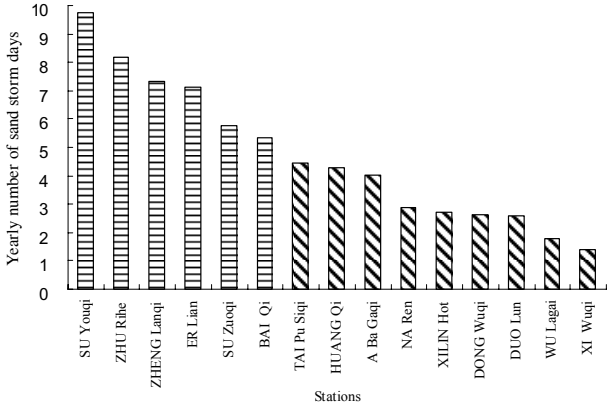

Fig. 4. Sand-dust storm regionalization at 15 meteorological stations.

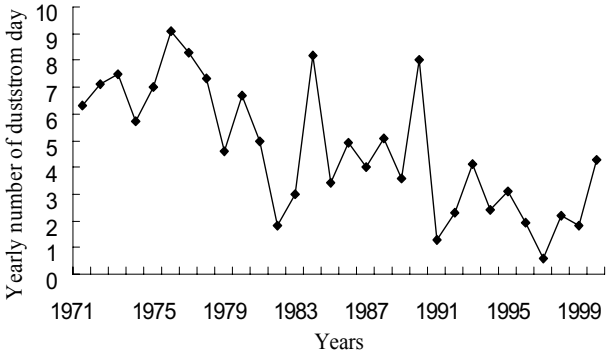

Fig. 5. Sand-dust storm year border change tendency chart in the Xilin Gol Area.

Table 3. Maximum number of sand storms in spring at 15 meteorological stations.

Station	Yearly number of sand-dust storm days	Sand-dust storm days of Spring in a year (%)	Sand-dust storm days of April in a year (%)
A Ba Gaqi	4	83	45
TAI Pu Siqi	4	89	42
DUO Lun	3	85	58
ZHENG Lanqi	7	78	43
BAI Qi	5	83	42
XI Wuqi	1	86	43
HUANG Qi	4	86	47
ZHU Rihe	8	80	43
SU Youqi	10	70	34
SU Zuoqi	6	76	47
NA Ren	3	86	52
ER Lian	7	70	37
DONG Wuqi	3	73	35
WU Lagai	2	89	40
XILIN Hot	3	67	34

dust storms actually has been aggravated in northern China. Before the 10th century the harm of sand-dust storms was once every 100 years, which increased to once every 2 years in the 1950s and 1960s. However, there has been a storm once a year since the 1990s. In recent years, with the increased development of society and the economy, the artificial unreasonable activity is intense; the vegetation and the surface structure receive heavy damage, the groundwater resources are ultra-picked and the subsoil water level drops rapidly year by year. These phenomena result in a worsening environment.

Records of sand storms at 15 meteorological stations in the Xilin Gol area can be seen in Fig. 6 and Table 3. The most sand storms occur in March, April and May in a year, especially in April, when there are the greatest numbers of sand-dust storms, 42.8% of the occurences of sand storms

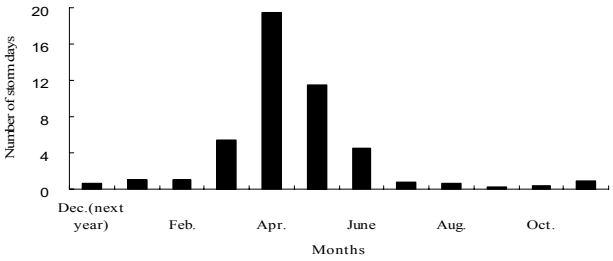

Fig. 6. Monthly changes in sand-dust storm frequency in the Xilin Gol Area.

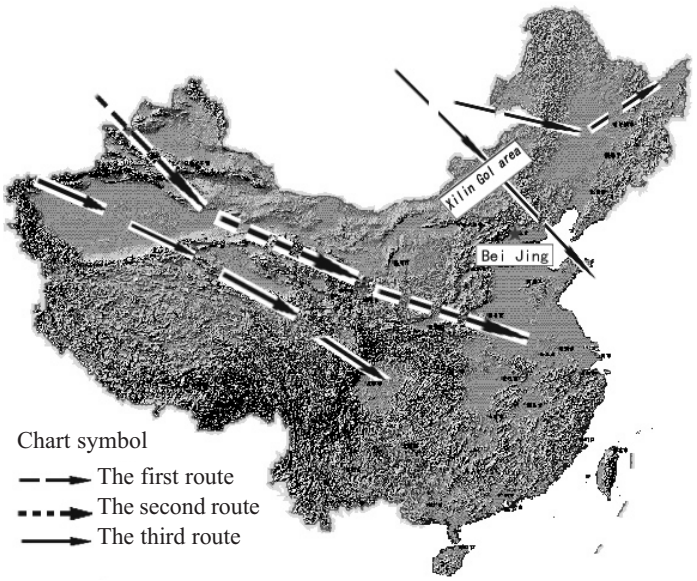

Fig. 7. The three routes of cold air in China.

for the whole year. After May, the times of sand storm drop sharply, and are the lowest in September and October. The frequency of sand storms in spring is related to strong spring winds, thawed ground, rising temperatures and scarce rainfall. Under these circumstances, sandy soil structure becomes loose. If a system of activity of strong weather arises, it is easy for sand storms to be produced.

Because of an increase in rain water, vegetation coverage is abundant in summer. In this case, sand storms could be restrained effectively. The yearly frequency of sand storms is lowest in autumn. The ground freezes in winter, which makes it difficult to cause sand storms: therefore, the frequency of sand storm also lowers in winter.

Spatial Distribution of Sand-Dust Storms

Spring is a season with strong winds, which are one of the main dynamics of sand storm creation in northern China. The cold air is a main factor for producing a sand storm [17]. There are three cold air routes that affect sand storms in China. The third route is that the cold air flows from the middle to the south of Mongolia, which affects northeastern China, east and middle Inner Mongolia and Beijing. The Xilin Gol area is in the third route, and it is an entryway for cold air coming from Mongolia (Fig. 7).

An isoline can be seen on the distribution map of yearly dates and numbers of sand storm from 15 meteorological stations in the Xilin Gol area from 1971 to 2000 (Fig. 8).

(1) Spatial distribution characteristics show that the date and number of storms is more obvious in the western area than in the eastern area. In the east, including XILIN Hot and DUO Lun, the annual mean number of yearly sand storms is 3 days, and in XI Wuqi, the annual mean number is only 1 day. In comparison, the annual mean number of yearly sand storm days increases in the west and is about 7 days. The annual mean number of yearly sand storms is 8.5 days in ZHU Rihe and 10 days in SU Youqi.

(2) Many sand storms arise around the Hun Shandake desert in north China, which can be explained by the rich materials as a source of sand storms that it provides.

(3) Sand storm occur in arid, semi-arid and semi-moist regions. Actually, the obvious differences in the distribution of sand storms in the Xilin Gol area are also related to vegetation cover. Typical prairie and meadow prairie are the main landscapes and vegetation cover rate is high in the east in Xilin Gol area, which can effectively prevent the migration of a sand storm. DUO Lun and A Ba Gaqi are a farming-pastoral ecotone in the middle of the Xilin Gol area of northern China [18]. But the western landscape is mainly wilderness prairie with a loose dry surface, which is a main source of sand for storms in the Xilin Gol area.

Conclusions

(1) Sand storms are disastrous weather events. Their arisal is closely related to climatic factors, including strong winds, average wind velocity, ground temperature,

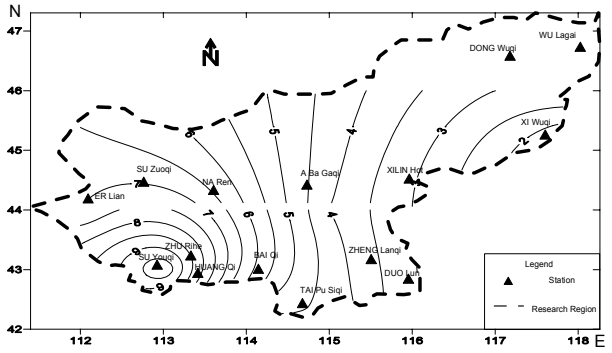

Fig. 8. Yearly sand-dust storm date and number isoline distribution map.

relative humidity, and days of snow. The correlation coefficient between sand storm days and strong wind days is highest, at 0.9 equally.

(2) The overall number of sand storms arising showed a declining trend from 1971 to 2000.

(3) The spatial distribution of sand storms in the Xilin Gol area shows that the annual mean number of sand storms in the western area is more than in the eastern area.

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