Impact factors of soil wind erosion in the center of Taklimakan Desert

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Abstract: The development and progress of soil wind erosion are influenced by the factors of climate, terrain, soil and vegetation, etc. This paper, taking Tazhong region, a town in the centre of the Taklimakan Desert, as an example and using comparative and quantitative methods, discussed the effects of climate, surface roughness (including vegetation cover) and surface soil properties on soil wind erosion. The results showed that the climate factor index *C* of annual wind erosion is 28.3, while the maximum of *C* is 13.9 in summer and it is only 0.7 in winter. The value of *C* has a very good exponential relationship with the wind speed. In Tazhong region, the surface roughness height is relatively small with a mean of 6.32×10^{-5} m, which is in favor of soil wind erosion. The wind erosion is further enhanced by its sandy soil types, soil particle size, lacking of vegetation and low soil moisture content. The present situation of soil wind erosion is the result of concurrent effects of climate, vegetation and surface soil properties.

Keywords: Taklimakan Desert; roughness; particle size; soil moisture content; soil wind erosion

1 Introduction

Wind erosion is the detachment, transportation and re-deposition of soil particles by wind. The result of wind erosion on agricultural soil is the loss of topsoil and nutrients, therefore, reduces crop yield. In arid and semi-arid region, wind erosion is one of the major reasons for land desertification. A sparse vegetation cover, a loose, dry and smooth soil surface, and strong winds all increase the risk of soil wind erosion. The mechanics and influencing factors of wind erosion have been investigated by many people for a long time. A semi-empirical equation for estimating wind erosion on soil was established by Woodruff *et al*. (1965). In this equation, the dust emission by wind erosion on a surface was expressed as the functions of soil erodibility, surface roughness, climatic factor, the length of farming field in the prevail wind direction and vegetation coverage. However, Gillette *et al.* (1988) suggested that the dust emission by wind erosion could be expressed as the function of wind speeds and the surface conditions. In another study, all the influencing factors of wind erosion were categorized as weather and climate conditions, soil conditions, surface roughness, soil utilization and management practices (Shao *et al*., 1997). He *et al*. (1997) carried out a preliminary simulation test on the influencing factors of wind erosion in wind tunnel. The tested factors included wind regimes, soil surface cover conditions, surface material composition and human factor. Some scholars investigated the wind regime in Tazhong region and explored the relationship between wind speed and sand transport rate (Zhao *et al.*, 1995; Wang *et al.*, 2001; Zu *et al.*, 2005). These studies, however, only took wind speed into account for wind erosion, lacking of a comprehensive analysis of all factors on wind erosion. This paper discussed the influences of climate, surface roughness (including vegetation cover) and surface soil properties on the wind erosion in Tazhong region.

2 Study area and data analysis

The study area is selected at Tazhong, where has a

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bare sand surface with serious wind erosion in the Taklimakan Desert (Fig.1). Spring and summer are windy seasons in this area. Wind combined with bared surface and low soil moisture frequently produces massive dust storms. The sand and dust storm weather occurs more than 200 days every year. The sand and dust storms bring many problems to local oil works. Also, those sand and dust storms produce a huge amount of dust aerosol, which may have a deep influence on regional and even global climate.

Fig. 1 The location of Tazhong region in the Taklimakan Desert

A long term weather station is run in Tazhong by the Desert Atmosphere and Environment Observation Experiment Station of Taklimakan Desert (83°40′E, 39°00′N, and 1,099.3 m a. s. l.). All data used in this study, including local meteorology, land surface characters, and land surface process (turbulence characteristic, parameter of soil erosion and dust emission and transportation), are provided by the research station.

3 Results and discussion

3.1 The role of climate factors on soil wind erosion

Climate factors play important roles in soil wind erosion. During the process of land desertification, a dry and windy climate is essential. The climate factors mainly include wind regime, precipitation, temperature, and humidity, among which wind speed is the primary factor because it is the most direct power source of soil wind erosion. The larger the wind speed is, the greater the erosion will be. Temperature and precipitation are also important factors affecting soil wind erosion. These two factors determine the drought degree of a region, and a drier soil is more feasible for wind erosion. Therefore, in evaluating the wind erosion potential of an area, the climate factors should be firstly taken into account in the evaluation process. Here, the equation recommended by FAO (1979) for calculating wind erosion potential was revised (Equation 1) and tested in Tazhong area.

$$C = \frac{1}{100}\sum_{i=1}^{12} u^3 \left(\frac{ETP_i - P_i}{ETP_i}\right) d. \qquad (1)$$

Where u is monthly average wind speed observed at 2 m height (m/s); ETP_i is monthly evaporation potential (mm); P_i is monthly average precipitation (mm); d is the number of days in a month. ETP_i can be calculated by the equation which is given by Cheng *et al.* (1980):

$$ETP_i = 0.19(20+T_i)^2(1-r_i). \qquad (2)$$

Where T_i is monthly average temperature; r_i is monthly average relative humidity.

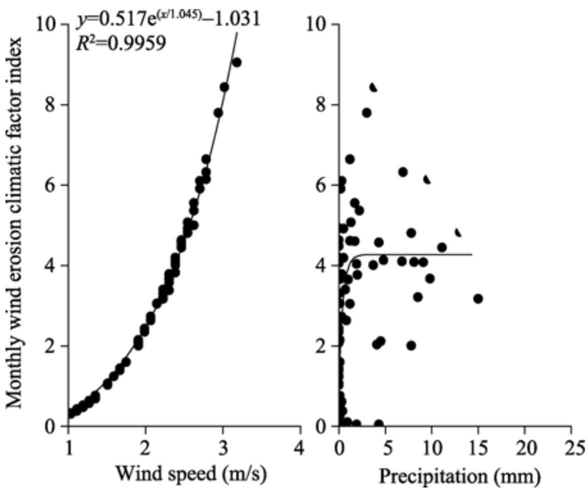

Fig. 2 The relationships of climatic factor index for monthly wind erosion with wind speed and precipitation in Tazhong region during the period of 1999–2008

Based on the data from 1999 to 2008 and Eqs. (1), and (2), the climate factor index (C) of the annual wind erosion was 28.3 in Tazhong region, which indicates that climate erosion ability was not strong. This is consistent with the result obtained by Dong *et al.* (1994). The value of C is high in summer (13.9), followed by spring and autumn, which is 9.9 and 3.8 respectively, and it is only 0.7 for winter. The relationships between the climate factor index of wind erosion (C), and monthly average wind speed and monthly precipitation in Tazhong were analyzed (Fig. 2). The results showed that C had a very good exponential relationship with wind speed with the correlation coefficient (R^2) of 0.9959. Its value becomes higher when wind speed increases. The C value, however, does not closely relate to precipitation, which implies that precipitation in Tazhong plays a less important role on wind erosion than wind speed does.

3.2 Surface roughness

Surface roughness (Z_0) is an important physical parameter related to land surface erosion. It means a height where the average wind speed decreases to zero. For a fixed location, the surface roughness Z_0 is often considered a constant if the surface properties had not changed (Wu, 1987). Its value varied depending on the terrain undulation, vegetation coverage and other factors. To some extent, the increase of surface roughness could control soil wind erosion, suppress blowing sand and improve ecological environment (Fryear, 1985). Thus, the surface roughness is one of the important factors for accessing soil wind erosion potential.

3.2.1 Vegetation coverage of surface

Vegetation coverage could change the surface roughness and affect wind speed. On the other hand, it could make the soil particles combine more tightly near the root zone and prevent them from wind force detachment. Raupach (1993) provided the following equation to evaluate the role of vegetation coverage on wind erosion:

$$R(\lambda)=\begin{cases}1 & \lambda=0\\ \sqrt{(1-m\sigma\lambda)(1+m\beta\lambda)} & \lambda>0\end{cases}. \quad (3)$$

Where $R(\lambda)$ is the index of vegetation coverage contribution to wind erosion; σ is ratio of the root area and the plain area, with an empirical value of 1.45; β and m are also empirical values with the value of 202 and 0.16 respectively; λ is shear area index of vegetation and determined by cover fraction of vegetation. It can be calculated by the empirical formula (Shao *et al.,* 1997):

$$\lambda=\begin{cases}0 & f=1\\ -0.35\ln(1-f) & f<1\end{cases}. \quad (4)$$

In the centre of Taklimakan Desert, vegetation is sparse and has a simple community structure. Except for the oilfield operation area, living area and both sides of the desert highway, the ground surface of Ta-Zong region is almost bare. Therefore, the shear area index λ of vegetation is approximately zero, and the value of $R(\lambda)$ is 1. Thus the effect of vegetation on the soil wind erosion is considered to be zero.

3.2.2 The surface roughness of Tazhong

Based on the wind tunnel experiment and field research work, Bagnold (1941) gave the equation of velocity distribution with height:

$$u=5.75u_*\lg\frac{Z}{Z_0}. \quad (5)$$

Where u is the wind speed (m/s); u_* is the friction velocity (m/s); Z is the observation height (m); Z_0 is the surface roughness (mm). After rearranging equation (5), the following equation could be obtained:

$$\lg Z_0=\frac{u_1\lg Z_2-u_2\lg Z_1}{u_1-u_2}. \quad (6)$$

Based on Eq. 6, if we know the wind speeds of two different heights, the surface roughness can be calculated. The data from April 1, 2007 to August 31, 2007 recorded by two automatic weather stations (one is located in flat sand land and the other is located in the tops of tall dune-chains in Tazhong area) were used to calculate Z_0 and obtained an average value of 5.11×10^{-5} m in flat sand land, and 7.53×10^{-5} m at the top of big dune-chains. The two values were averaged to get the average surface roughness height, which is 6.32×10^{-5} m in Tazhong region. This value is closed to the value of flat sand in Mu Us Desert (Mei *et al.,* 2006).

Table 1 showed the wind tunnel test results of wind erosion modulus of various surfaces at different wind speeds (Liu *et al.*, 2000). From Table 1, we can see that the wind erosion ability became bigger when the surface roughness height became smaller. Using Table 1, we have analyzed the relationship between surface roughness height and wind erosion modulus and calculated the wind erosion modulus of Tazhong region at different wind speeds. The results showed that the wind erosion modulus of Tazhong region was bigger than those of other regions at the same wind speed. So the relative small surface roughness height has actually aggravated the wind erosion in Tazhong region.

3.3 Land surface properties

Physicochemical properties of surface soil have a significant influence on the occurrence and development of wind erosion. This paper analyzed the effects of soil types, soil particle size and soil water content on wind erosion.

Table 1 The relationship between roughness length and the amount of wind erosion

Sampling area	Roughness (m)	Wind erosion modulus at different wind speeds ($kg/(m^2 \cdot h)$)				
		8	10	15	20	25
Grassland	1.42×10^{-3}	−6.022	0.483	6.995	13.058	23.692
Cultivated land	6.30×10^{-4}	0.932	12.221	30.855	39.603	58.630
Sand land	1.83×10^{-4}	20.704	51.504	103.611	147.918	239.070
☆Tazhong	6.32×10^{-5}	31.814	75.280	145.817	219.634	371.910

3.3.1 Types of surface soil

Soil erosion is related to the regional geological environment and is affected by the soil texture (Jilili *et al.*, 2002, 2010). Soils with various textures have different water contents, water retention, gummy cohesion and plastic pressure of soil particles. Accordingly, under the same wind speed, the degrees of soil erosion are different for different soils. Based on the soil classification of the U.S. Department of Agriculture, sandy clay, loam and clay are categorized according to the percentages of sand, silt and clay in the soil (Shao *et al.*, 2001). Without considering other factors, loam soil is more easily eroded by wind than clay soil, while sandy clay soil is most easily eroded. Lu *et al.* (1999) and Shao *et al.* (2001) have studied the plasticity of various soils. The results showed that the horizontal component of the plastic pressure (Ps) of the sandy clay soil usually was 20, while the Ps of loam was only 0.5 and that of clay was 350. Ps is a physical parameter which represents the soil erodibility and is determined by the soil density. Soils with textures such as sandy clay and loam have a small Ps and big erodibility. Compact soil has a relatively larger Ps and smaller erodibility. According to the particle-size distribution of the surface soil in Tazhong region, the soil is sandy clay which is loose, ventilatory and permeable. This type of soil has large pore space among particles. In addition, they lack plasticity, cohesive property and sticking tendency. The strong wind credibility combined with this easy eroded soil makes Tazhong a strong wind erosion region (Li *et al.*, 2006; Wang *et al.*, 2006; Wu *et al.*, 2006).

3.3.2 Particle size of surface soil

Soil particle size also has the effect on wind erosion. The larger the particle size is, the more energy will be needed to move soil particles and, therefore, the chance of wind erosion occurs. Table 2 showed the particle size parameters of some soil samples taken from the Tazhong region. The 17 samples were collected either from dunes or the land between dunes. Most samples have the particle sizes ranging from 100 μm to 250 μm that belong to fine sand. Only the particle size of the sample No.17 is less than 100 μm that belongs to very fine sand. The average particle size is 136 μm. According to the formulas of threshold velocity which was given by Shao *et al.* (2000), we calculated the starting velocities of different sands in the Tazhong (Fig. 3). The smaller the particle size is, the stronger the inner viscous force will be, and this increases the threshold fraction velocity u_{*t}. u_{*t} has a minimum value about 0.24 m/s when the particle size is 100 μm. When the particle size increases, the inner viscous force decreases gradually and the gravity increases gradually at the same time. The average particle size of the sand in Tazhong region is 136 μm, which is close to the size that has the smallest starting velocity. This indicates that, in the aspect of sand size,

Table 2 The particle size parameters of surface soil in Tazhong region

No. of sample	Mz (μm)	σ	SK_1	KG
1	132	0.69	0.05	0.99
2	142	0.49	0.01	0.96
3	145	0.58	0.00	0.94
4	140	0.51	0.02	0.97
5	154	0.54	0.01	0.95
6	136	0.59	0.00	0.94
7	161	0.72	0.11	0.97
8	152	0.61	0.00	0.94
9	137	0.48	0.00	0.96
10	129	0.54	0.01	0.95
11	136	0.48	0.00	0.96
12	144	0.48	0.01	0.96
13	130	0.62	0.02	0.94
14	131	0.47	0.00	0.96
15	126	0.47	0.00	0.96
16	123	0.42	0.00	0.96
17	99	0.70	0.08	1.04

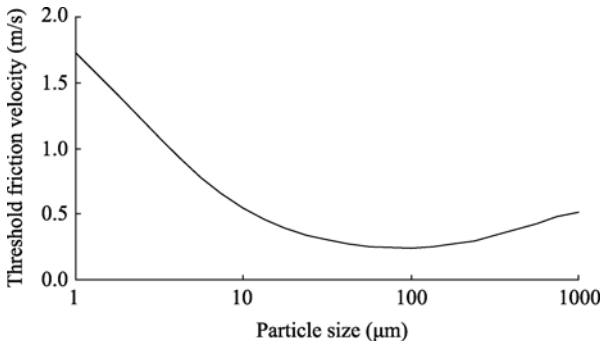

Fig. 3 The variations of threshold friction velocity with particle size in Tazhong region

Tazhong region is more easily to suffer from wind erosion and the intensity of wind erosion is stronger than other regions under the same wind speed.

3.3.3 Moisture content of surface soil

Moisture content of surface soil is also an important factor to affect soil wind erosion. Regional soil moisture depends on precipitation, evaporation and soil water retention in the region. If soil is humid, the viscosity of soil would increase and aggregation between soil particles be enhanced, and then the critical friction velocity, windblown sand speed and sand transport rate would be changed. Fecan *et al.* (1999) and Dong *et al.* (2002) have carried out a lot of works in this field and established the equations:

$$\begin{cases} H(w) = 1 & w \le w' \\ H(w) = \sqrt{1 + a(w - w')^b} & w > w' \\ w' = 0.0014(clay\%)^2 + 0.17(clay\%) \end{cases}, \quad (7)$$

$$H(w) = \sqrt{1 + kw} \,. \quad (8)$$

Where $H(w)$ is an index that represents the effect of soil moisture on wind erosion; w is volumetric water content of surface soil (‰); w' is critical value; a and b are empirical constants whose values depend on soil type; *clay*% is the percentage of clay in soil; k is proportional coefficient with value ranging from 1.5 to 3.0. Shao *et al*. (2001) has given the values of w', a and b to various soils based on the research on Fecan *et al*. (1999). In those values, the critical value of sandy soil's moisture was the smallest, only 5‰ while the critical value of clay was the biggest, 17‰. This indicates that in the process of wind erosion, the response of sandy soil to the water content is very sensitive.

Figure 4 shows the soil moisture contents at 5 cm and 10 cm depths of a soil profile in Tazhong region from January to August of 2008. The soil moisture contents at 5 cm and 10 cm depths from January to March were relatively higher than that in other times. From January to March, the soil moisture content at 5 cm depth was about 0.4 g/kg while from April to August it was near 0. The maximum of 10 cm depth soil moisture content appeared in March, which was 9.49 g/kg. From April to August the soil moisture content at 10 cm depth was lower than 8 g/kg. On average, the soil moisture contents at 5 cm and 10 cm depths were lower than 5 g/kg from January to August. Tazhong region is dominated with sandy soil, so the value of w' is 5 g/kg, which is larger than the mean value of soil moisture contents at 5 cm and 10 cm depths. Based on the Eqs. (7) and (8), we obtained $H(w)$ of 1, which indicated the effect of moisture content on wind erosion can be neglected.

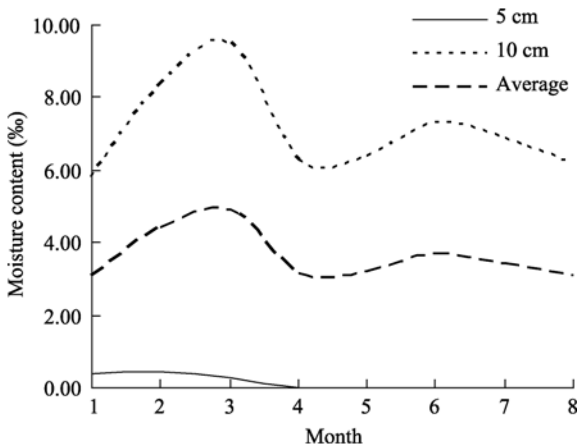

Fig. 4 The moisture content of surface soil in Tazhong region from January to August of 2008

4 Other impact factors

Based on the wind-tunnel test, Nickling (1981) suggested that the content of soil salt in ground surface also had an effect on wind erosion. Soil hardness is factor compacting wind erosion. Now, there is no good method for determining the soil hardness value, and it was given 1 during a study on wind erosion by Shao *et al.* (2001).

5 Conclusions

The purpose of this paper was to analyze the factors compacting soil wind erosion in Tazhong region. By analyzing the climate factor index, we found that the wind erosion contributed from climate factor was not big in Tazhong region. The climatic factor index has a very good exponential relationship with wind speed, and its value became larger when wind speed increased. The climate factor index negatively related to precipitation, but the relation was not strong.

Our research indicated that, in Tazhong region, the average surface roughness height, Z_0, is only 6.32×10^{-5} m, indicating a surface that was more erodible.

The soil in Tazhong region is loose and lack of plasticity and cohesiveness and those properties make it easily be eroded by wind. The average particle size of the soil in Tazhong region is close to the size in which the lowest starting velocity occurs, and this indicates that the power which needs to move the sand here is small comparing with those of other places. The moisture content of surface soil is very low. The mean values at 5 cm and 10 cm depths in Tazhong were lower than 5 g/kg from January to August, which resulted in a low viscosity between soil particles and made soil more erodible. The present situation of soil wind erosion is the result of concurrent effects of climate, vegetation and surface soil properties.

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