

## Dynamics of dust storm and its response to meteorological conditions and anthropogenic impact in South edge of Taklimakan desert, China

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**सार** – इस अध्ययन में, चीन के तकलीमाकन रेगिस्तान के दक्षिणी किनारे पर स्थित एक विशिष्ट नखलिस्तान में अंधड़ की आवृत्ति के अलग-अलग प्रवृत्तियों का विश्लेषण समय श्रृंखला विश्लेषण और समाश्रण मॉडल का उपयोग करके किया गया। 2004-2018 की अवधि के लिए LUCC (भूमि उपयोग / कवर परिवर्तन) डेटा, एनडीवीआई (सामान्यीकृत अंतर वनस्पति सूचकांक) रिमोट सेंसिंग डेटा, मौसम संबंधी डेटा और धूल तूफान आवृत्ति डेटा स्थानीय स्टेशन और ईआरडीएस (पृथ्वी संसाधन डेटा विश्लेषण प्रणाली) से एकत्र किए गए। सॉफ्टवेयर, मानव गतिविधियों, प्राकृतिक कारक और अंधड़ की आवृत्तियों के बीच बहुचर संबंधों का विश्लेषण प्रिंसिपल कंपोनेंट एनालिसिस (पीसीए) का उपयोग करके किया गया। परिणामों ने संकेत दिया कि अध्ययन अवधि में वार्षिक अंधड़ की आवृत्ति उतार-चढ़ाव के साथ बढ़ी है। मासिक अंधड़ की आवृत्ति मार्च और जून के महीनों के बीच उच्च मानों को दर्शाती है, जो वार्षिक अंधड़ की आवृत्ति का 72.3% है। वर्षा और हवा की गति मौसम संबंधी दो कारक हैं जो अंधड़ के गठन और उसकी आवृत्ति को प्रभावित कर सकते हैं। अंधड़ की आवृत्ति और तापमान के बीच संबंध महत्वपूर्ण थे। इसके अलावा, मानवीय गतिविधियों ने परोक्ष रूप से वनस्पति आवरण और प्रत्यक्ष रूप से धूल उत्सर्जन ने अंधड़ की गतिशीलता को प्रभावित किया। इसके अलावा, बहुचर विश्लेषण से अंधड़ की आवृत्ति, मौसम संबंधी कारकों और NDVI के बीच एक स्पष्ट संबंध पर प्रकाश डाला गया है। मुख्य कंपोनेंट पर अंधड़ की आवृत्ति, वर्षा, हवा की गति और एनडीवीआई के उच्च लोडिंग से पता चला है कि वर्षा और एनडीवीआई में वृद्धि और अंधड़ की आवृत्ति में कमी आएगी, जबकि उच्च हवा की गति अंधड़ की आवृत्ति को बढ़ाएगी। इस अध्ययन के निष्कर्ष अंधड़ के संभावित कारणों को समझने में उपयोगी हो सकते हैं, जो अंधड़ के स्रोत क्षेत्र को नियंत्रित करने के लिए आधार प्रदान कर सकते हैं और पर्यावरण पर अंधड़ के नकारात्मक प्रभावों को भी कम कर सकते हैं।

**ABSTRACT.** In this study, the varying trends of dust storm frequency in a typical oasis located at the South edge of Taklimakan desert, China were analyzed by using time series analysis and regression models. The LUCC (land use/cover change) data, NDVI (Normalized Difference Vegetation Index) remote sensing data, meteorological data and dust storm frequency data for the period of 2004-2018 were collected from local station and ERDAS (Earth Resources Data Analysis System) software, the multivariate relationships between human activities, natural factor and dust storm frequencies were analyzed by using Principal Component Analysis (PCA). Results indicated that the annual dust storm frequency in the study period increased with fluctuation. The monthly dust storm frequency shows higher values between the months of March and June, which accounts for 72.3% of the annual dust storm frequency. Precipitation and wind speed are two meteorological factors which can impact the dust storm formation and its frequency. The correlation between dust storm frequency and temperature was insignificant. Moreover, human activities indirectly affected the dynamics of dust storms by changing the vegetation cover and direct dust emissions. Furthermore, multivariate analysis highlighted a clear relationship among dust storm frequency, meteorological factors and NDVI. The high loadings of dust storm frequency, precipitation, wind speed and NDVI on a PC indicated that increase in precipitation and NDVI will decline dust storm frequency, whereas higher wind speed will enhance dust storm frequency. The findings of this study could be useful to understand the possible causes of dust storms, which can provide the basis for controlling the dust storm source region and also mitigation of the negative effects dust storm on the environment.

**Key words** – Dust storm, Variation trends, Meteorological conditions, LUCC, PCA, Taklimakan desert.

### 1. Introduction

The Taklimakan Desert is the second largest shifting sand desert in the world. This desert and its adjoining

areas are highly vulnerable to the impacts of dust storms (Zhang *et al.*, 2015; Liu *et al.*, 2004). Particularly, frequent spring dust storms cause serious environmental problems which has negative impacts on human society at

the south edge of this desert (Aili and Kim Oanh, 2015; Yan *et al.*, 2016). In a previous research the entire Taklimakan Desert was selected as a study area and pattern of spatial-temporal changes of dust storms were evaluated with limited meteorological observations. For instance, Cheng *et al.* (2014) studied the spatial and temporal features of hot and cold spots of dust storms in Xinjiang region (Cheng *et al.*, 2014). In another study Liu and Wei (2005) analyzed the variation trends of dust storm frequency in southern Xinjiang with the help of long-term meteorological data. They described that under global warming conditions, frequency of dust storms will be reduced due to reduction in strong winds and a parallel increase in precipitation over the past 60 years (Liu and Wei, 2005). However, there is a lack of scientific efforts on dust storm studies for the specific region of Taklimakan Desert. Therefore, this study was conducted to partly fill in this information gap.

Since information about dust storm studies regarding Taklimakan Desert is limited so this particular study was performed to partly fill this knowledge gap. The southern edge of the Taklimakan Desert has already become an ecologically fragile area due to frequent occurrence of dust storms in this region (Wang *et al.*, 2017). In this study, the Moyu County in Hetian Oasis was selected as study area. The dust storm frequency changing trends in the period of 2004-2018 are combined with meteorological data (wind speed, temperature and precipitation), LUCC data and NDVI data. This combined data was then used to analyze the possible impacts of meteorological conditions and human development activities on the variable trends of dust storm frequency.

## 2. Materials and method

### 2.1. Overall characteristics of the study area

Moyu County is selected as study area. This county is located at the southwest of Xinjiang Uygur Autonomous Region, North Slope of Kunlun Mountain and south edge of Taklimakan Desert (Fig. 1). Geographical coordinates are 36°36' ~ 39°38' N, 79°08' ~ 80°51' E, The total area of Moyu County is 25788.86 km<sup>2</sup>, including 16 town/townships, total population is 632740 (Yan *et al.*, 2016; Shao *et al.*, 2019).

The topography of Moyu County is high in the south and low in the north, altitude between 1120 and 3663 m. Its southern part is a mountainous area with undulating hillsides and central part is a flood alluvial fan plain. Climate condition of Moyu County belongs to warm temperate dry desert climate, with distinct seasons; summer is hot, dry and less rain; temperature rise rapidly in spring. Sparse precipitation, abundant light, long frost-free period, large temperature difference between day and night is the

main meteorological characteristics of Moyu County. The annual average temperature is 11.3 °C, the monthly average temperature shows highest value in July (26.4 °C) and lowest value in January (-6.5 °C), the extreme minimum temperature is -18.7 C, the annual average precipitation is 36-37 mm, the annual evaporation is 2239 mm, the frost-free period is 177 days and the annual sunshine time is 2655 hours (Shao *et al.*, 2019; Li and Zheng, 2020).

Dry climate and large area of desert provide favorable conditions for frequent dust weather. The annual dusty days in Moyu County is more than 200 days and the strong sand storm weather can reach about 60 days. In this study, dust storm weather were classified into 3 levels depending on the severity, using the criteria given by AQSIQ/NSC (2006). The weaker type of dust storm is called the suspended dust weather and refers to the suspending dust in the air under calm or low wind conditions. The medium severe type of dust weather is called the blowing dust with the horizontal visibility ranges from 1 km to 10 km. The most strong dust weather is called sand storm which refers to such phenomena when the instantaneous wind velocity is over 25 m/s and horizontal visibility of air is below 1 km (AQSIQ, 2006). The number of dusty days in spring and summer accounted for approximately 90% of the total number of dust storm days in a year. From April to August is the high occurrence period of dust storm, May and June were the most active periods of dust storm.

### 2.2. Data collection

#### 2.2.1. Dust storm frequency and meteorological data

In this study classification of dust storm weather was based on the criteria given by AQSIQ/NSC (2006). The total number of the three types of dust weather was treated as annual dust storm frequency. Meteorological data (temperature and wind speed) in the period of 2004-2018, were obtained from the Moyu Meteorological Station and the China Meteorological Data Sharing Service System (<http://cdc.cma.gov.cn/>).

#### 2.2.2. LUCC data

Seven types of LUCC data including agricultural land, grassland, orchard, wetland forest, residential & industrial land and unused land were used in this study. The above mentioned land types were classified according to the criteria given by the National Standard Committee of China (GBT 21010-2007). As dust storm events in the study area spread over larger areas including the entire Taklimakan Desert and its surrounding areas (Aili and Kim Oanh, 2015; Gao *et al.*, 2015), so the LUCC data were collected from the entire southern

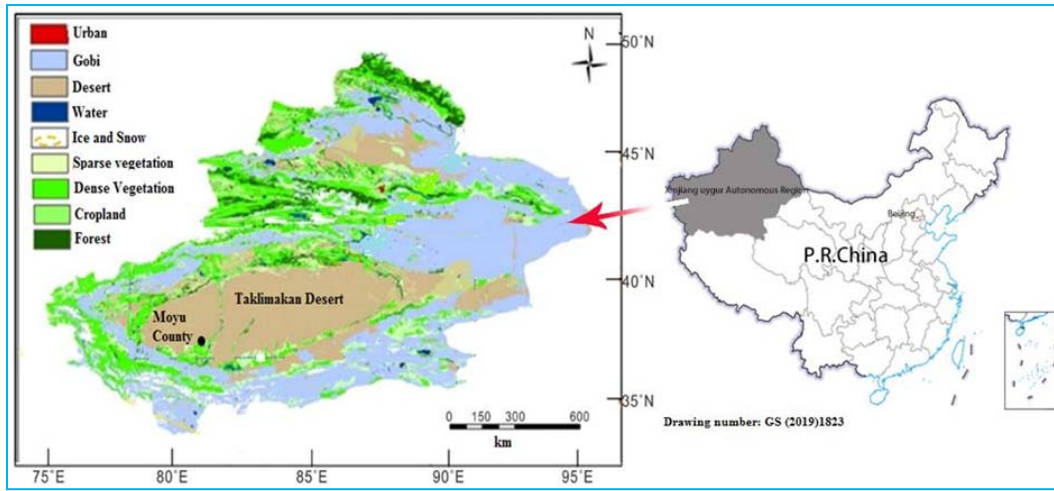


Fig. 1. Location and surrounding environment of study area

Xinjiang region, including Bayingolin Mongol Autonomous district, Aksu prefecture, Kizilsu Kirgiz autonomous district, Kashgar prefecture and Hotan prefecture in the period of 2004-2018 and the relationships between LUCC and dust storm frequency were analyzed. Population data were collected from the Xinjiang statistical yearbook (2004-2018).

2.2.3. NDVI data

ERDAS image software was used to get annual mean value of NDVI from 2004-2018. For this purpose, the entire southern Xinjiang region (36° - 42° N and 78° - 93° E) is divided into 360 grid cells of 0.5° × 0.5° for calculating the NDVI value. The remote sensing (Landsat 7) map is extracted from the Earth Explorer website (<http://earthexplorer.usgs.gov/>) based on the geographical coordinates of the study area. In each year month of August was selected to obtain NDVI value mainly due to higher vegetation cover and clear air (fewer clouds), whereas July was selected for 2007, 2009 and 2017, because the remote sensing image was not available or unclear in August during these years. For every 360 grid cells NDVI values were obtained from ERDAS image software, these values were then averaged to generate annual mean NDVI value.

2.3. Statistical analysis

Simple time-series analysis technique was used to find out the relationship among annual dust storm frequency, corresponding meteorological factors and LUCC. This statistical tool can elaborate the relationship between two variables on the basis of observed data. Additionally, it can also estimate the value of the dependent variable by considering the value of the independent variable (Zaiontz, 2015). For example, if  $y$  is

a dependent variable and  $x$  is an independent variable, then the linear regression model provides a prediction of  $y$  from  $x$  in the form of:

$$y = \alpha + \beta x + \varepsilon \tag{1}$$

where:  $\alpha + \beta x$  is the deterministic portion of the model and  $\varepsilon$  is the random error.

To further explore the multivariate relationships between dust storm frequency and other factors, the PCA with a Varimax rotation was applied (Zaiontz, 2015; Ivits *et al.*, 2013). As compared to unrotated Empirical Orthogonal Function (EOF) and Singular Value Decomposition (SVD), the Varimax rotation criterion maximizes the sum of the variances of squared coefficients within each eigenvector and the rotated axes remain orthogonal.

For example, let  $X = [x_i]$  be any  $k \times 1$  random vector. We now define a  $k \times 1$  vector  $Y = [y_i]$ , where for each  $i$  the  $i^{\text{th}}$  principal component of  $X$  is

$$y_j = \sum_{i=1}^k \beta_{ij} x_i \tag{2}$$

where,  $\beta_{ij}$  is a regression coefficient; since each  $y_i$  is a linear combination of the  $x_j$ ,  $Y$  is a random vector.

A total of 15 variables, including annual frequency of three types of dust storm weather (suspended dust, blowing dust and sand storm), three meteorological factors (annual precipitation, annual wind speed and annual mean temperature), seven types of land (agricultural land, forest, orchard, grassland, wetland, residential & industrial land and unused land), population and annual mean NDVI value were analyzed

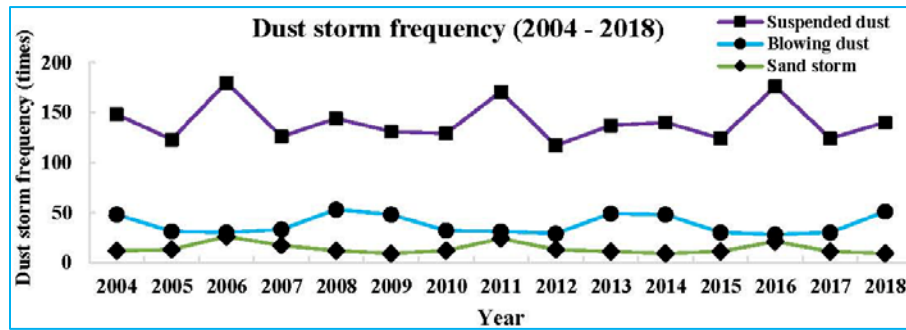


Fig. 2. Annual frequency of 3 types of dust storm (2004-2018)

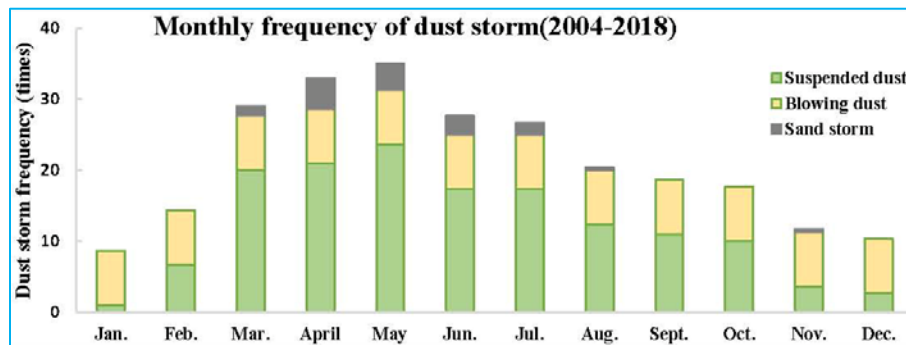


Fig. 3. Monthly average frequency of 3 types of dust storm (2004-2018)

using PCA. The NDVI value is obtained using the following formula:

$$NDVI = (\lambda_{NIR} - \lambda_{RED}) / (\lambda_{NIR} + \lambda_{RED}) \quad (3)$$

where,  $\lambda_{NIR}$  and  $\lambda_{RED}$  are the reflectance in the near infrared (central wavelength of 0.63-0.67 $\mu$ m) and red bands (central wavelength of 0.85-0.88  $\mu$ m), respectively.

### 3. Results and discussion

#### 3.1. Variation trends of dust storms

A total of 2347 dusty days were reported during the period of 2004-2018 with an annual mean of 189.3 dusty days. The annual frequency of the three types of dust weather is presented in Fig. 2. Three peaks of dust storm frequency can be found in this period, 2006(180d), 2011(171d) and 2016(176d). The decreasing trend is more conspicuous in the period of 2012-2016 than other period (Fig. 2).

The monthly average dust storm frequency value in the period of 2004-2018 is given in Fig. 3. It is obvious from Fig. 3 that the total number of dusty days in May accounts for 28.2% of each year, followed by April (21.1%), March (15.3%) and June (14.2%). Overall,

79.2% of the total annual dust storms appeared in these four months (Fig. 3). The minimum dusty days appeared in winter (November to February).

#### 3.2. Relationship between dust storm frequency and meteorological factors

Wind speed is the most vibrant factor which is responsible for dust storms. It was noted that if land surface conditions are suitable, even relatively weak winds can initiate dust storm events. In spring season, when low atmospheric pressure system prevails in the study area whereas the Siberian and Mongolian high pressure systems transfer to study area from north and northeast direction. This synoptic situation persuades strong wind consequently dust storm frequency increases in study area. The strong positive correlation can be found between annual wind speed and dust storm frequency with high statistical significance ( $R^2 = 0.84$ ).

Precipitation was negatively correlated with the dust storm occurrence frequency with higher statistical significance ( $R^2 = 0.54$ ). This is because the precipitation can increase soil moisture and vegetation coverage and reduce the likelihood of dust events.

It is also found that hydrothermal conditions and dust storms are not linearly associated. For instance, higher

temperature can increase vegetation growth, causing large vegetation coverage and decline in surface winds which ultimately suppress the occurrence of dust storms. However, higher temperature without parallel increase in precipitation will induce drought and boost surface dust emission, thereby, facilitating dust storm outbreaks. There was some correlation between annual dust storm frequency and temperature but it is not statistically significant ( $R^2 = 0.15$ ).

### 3.3. *Relationship between dust storm frequency and anthropogenic impacts*

#### 3.3.1. *Land surface cover and dust storm occurrence*

Dust storms occur not only due to natural factors but also because of human activities such as overgrazing and deforestation, which decline the vegetation cover (Xu *et al.*, 2006; Shi *et al.*, 2010; Fu *et al.*, 2016; Shen *et al.*, 2016). Therefore, variation trend analysis of dust storms is conducted by including other indicators of land use/cover changes using a series of long-term observation data. A large proportion landscape in this area is occupied by barren deserts, the Gobi desert and scarce grasslands. It was expected that the dust storms in the study area are directly related not only to the LUCC in the study area but also to the entire desert and its surrounding area. Therefore, the historical LUCC data from whole southern Xinjiang region, having a total area of 1,100,000 km<sup>2</sup>, was considered while studying the relationship between incidence of dust storm and the LUCC. Among the seven land types, area of grassland, wetland and unused land was reduced while the other four land types were expanded from 2004 to 2018. It was found that an area of 24,189 km<sup>2</sup> of unused land and 67,750 km<sup>2</sup> of grassland disappeared during the entire study period. So it can be supposed that the grassland and unused land might have converted into other forms of land uses.

Reduction in wetland area could be attributed to rapid increase in population with higher demand for water resources in southern Xinjiang that resulted in the drying up of natural lakes or shrinking of rivers (Lei and Zhang, 2005). There was no significant correlation between particular LUCC and dust storm occurrence but the NDVI has been found to be negatively correlated with dust storm frequency ( $R^2 = 0.45$ ). In addition to the Gobi and mobile deserts in the southern Xinjiang region, there exist large areas of transit zones between the oasis and the desert, which are called as “ecological fragile region”. These areas are actually meant for protection of oasis against desertification and dust storms but currently they are utilized for planting, grazing and urban construction (Lai *et al.*, 2002). At the same time rapid desertification has also been noted in agricultural and pastoral areas in the

southern Xinjiang region. Increase in agricultural, industrial & residential, forest and orchard land has been observed during 2004 to 2018. With these developments population also increased in the region, which may be linked to the China Central Government’s new western development strategy. According to an estimate large number of immigrants have moved to southern Xinjiang since the late 1990s (Lei and Zhang, 2005; Chen *et al.*, 2009).

#### 3.3.2. *NDVI and Dust storm occurrence*

To study the relationship between vegetation cover changes and incidence of dust storm during the period of 2004-2018, the annual NDVI values were obtained from ERDAS image software. These NDVI values were different for different landscapes. For instance the NDVI value for mobile desert ranged between 0.05-0.06, the Gobi Desert is 0.07-0.09 and for the fixed dunes it is 0.12-0.17. In case of forest land the value is 0.55-0.70, the grassland is 0.60-0.75 and the farmland is 0.65-0.83. Principally NDVI values range from -1 to +1, a value of 0.5 represents dense vegetation while values less than zero means no vegetation (Xu *et al.*, 2006; Sruthi *et al.*, 2015; Zhou *et al.*, 2018). To find a relationship between change in vegetation cover and dust storm occurrence a simple time-series analysis was used as shown in Fig. 4 As large areas were covered by mobile desert, fixed dunes and barren land, so the selected monthly mean NDVI value of the entire area was low (0.108-0.138). However there was fluctuations in NDVI value which indicated a decreasing trend after 2008, indicating decrease in vegetation cover during this period. A negative correlation has been found for the whole study period ( $R = -0.67$ ,  $P = 0.001$  and  $R^2 = 0.45$ ).

For the entire study period (2004 to 2018) agricultural land increased from 15,915 km<sup>2</sup> to 17,662 km<sup>2</sup>, the forest area increased from 31,564 km<sup>2</sup> to 36,895 km<sup>2</sup> and orchard increased from 1,124 km<sup>2</sup> to 2,814 km<sup>2</sup>. Overall increase in total land area was 8,768 km<sup>2</sup> from 2004 to 2018. On the other hand area of grassland was declined from 254,197 km<sup>2</sup> to 186,447 km<sup>2</sup>, *i.e.*, by 67,750 km<sup>2</sup> during this period. This decline in grassland area was much higher as compared to total increase in three types of land, *i.e.*, forest, orchard and agricultural land. Due to this reason the average NDVI value of the entire southern Xinjiang region indicated a declining trend in this duration.

### 3.4. *Multivariate association between dust storms, meteorological factors and the LUCC*

Principal component analysis was used to further elaborate the relationship among dust storm occurrence, LUCC and meteorological elements. (Yan *et al.*, 2016;

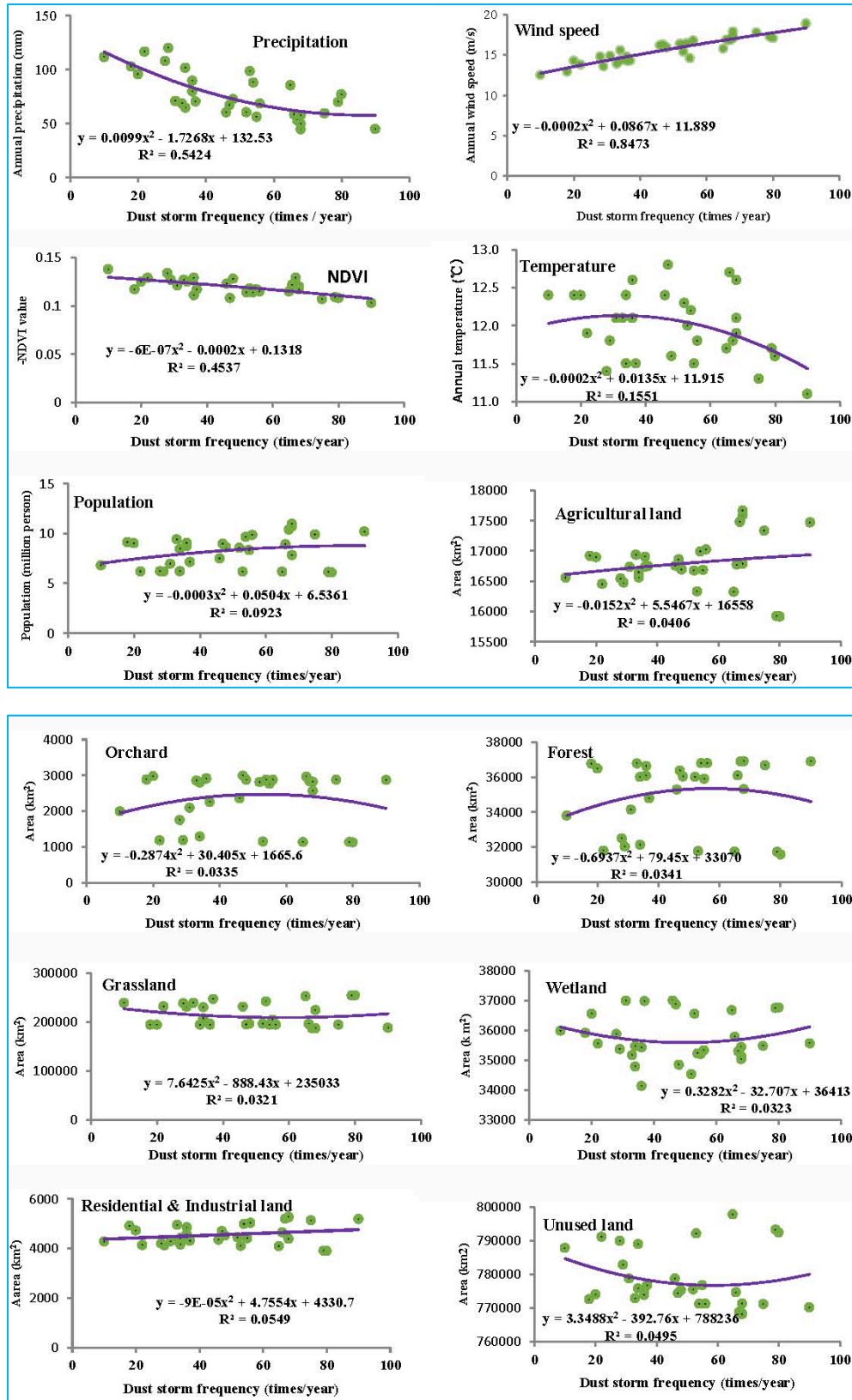


Fig. 4. Linear regression between annual dust storm frequency with annual meteorological factors, LUCC, NDVI (representative values for each year) and population (2004-2018)

**TABLE 1**

**Multivariate association between dust storm, meteorological factors and LUCC**

Variables	Principal components		
	1	2	3
Frequency of suspended dust	0.049	0.835	-0.098
Frequency of blowing dust	0.082	0.513	0.012
Frequency of sand storm	-0.039	0.409	0.087
Precipitation	-0.451	-0.792	-0.003
Temperature	0.192	-0.103	0.552
Wind speed	0.113	0.686	-0.091
Population	0.593	0.267	0.034
NDVI	-0.002	-0.835	-0.118
Agricultural land area	0.441	0.047	-0.084
Orchard area	0.633	0.067	0.186
Forest area	0.549	0.182	0.134
Grassland area	-0.714	-0.035	0.006
Wetland area	-0.583	0.130	0.657
Residential & Industrial land area	0.663	0.149	-0.042
Unused land area	-0.643	-0.123	-0.145
Percentages of variance (%)	49.3	31.2	7.4
Communality percentages of variance (%)	49.3	80.5	87.9

Note : Extraction method: Principal Component Analysis. Rotation method: Varimax with Kaiser Normalization

Jiang *et al.*, 2016). The results of the PCA are presented in Table 1.

The PCA with a Varimax rotation generated three principal components (PC), which can clearly explain 87.9% of the total variance of the original dataset, as presented in Table 3.

Component 1, explains 49.3% of the variance. It carries information regarding population, land use types of agricultural land, orchard, forest and residential & industrial land areas with positive loadings, while information about precipitation, wetland, grassland and unused land areas have negative loadings. The agricultural, residential & industrial lands forest and orchard lands and were extended and revealed positive correlation with population growth. During the same time period as grassland, wetland and unused land were changed into other land types, so they had a negative correlation with population growth and other land types.

Component 2, which explains 31.2% of the total variance, revealed high positive loadings for frequency of three types of dust storm weather (suspended dust,

blowing dust and sand storm) and wind speed, while negative loadings for NDVI value and precipitation. Precipitation is required to increase vegetation growth and high vegetation cover can decrease dust storm incidence. Hence, as a direct consequence of vegetation cover, the NDVI value has positive correlation with precipitation but it is negatively correlated with occurrence of three types dust storm. In addition, as a major driving force of dust storms, a positive correlation has been found between the wind speed and dust storm frequency with a high loading. The third component explains 7.4% of the total variance with high loadings of temperature and wetland, that indicates there probable positive association.

It is obvious that dust storm events occur as a consequence of combined effects of wind meteorological as well as land use factors. However, land use factors can be linked more with human activities which greatly influence the dynamics of dust storms by altering the vegetation cover which ultimately affects dust emission. Human development activities, such as excessive cultivation, over grazing, forest cutting and over-exploitation of water resources significantly reduced the vegetation cover. It was obvious that the NDVI would show more significance in component 1 where most of the human variables were present. The linear regression analysis in Fig. 4 also indicated the same relationship.

#### 4. Conclusions

(i) Significant correlation existed between dust storm frequency and wind speed. Being the major dynamic force behind dust storm formation the wind characteristics play a major role in deciding the size, duration and intensity of dust storms. The annual precipitation was found to be negatively correlated with dust storm events. Precipitation enhances vegetation growth, increase soil moisture hence reduces the likelihood of dust events. This study did not show any significant correlation between dust storm frequency and temperature mainly due to the involvement of many variables. Specifically, when temperature surpasses a threshold value, vegetation cover, wind speed and other drivers would influence the onset of dust storm events more than temperature.

(ii) Vegetation cover is an important land surface feature that influences dust storm frequency. The surge in vegetation can inhibit the incidence of dust storms. A linear regression between the NDVI and dust storm incidence in the study area manifested a negative slope. Formation of dust storms can also be influenced by population growth as it changes certain land surface characteristic. Rapid increase in population replaced the forest land, grassland and other non-cultivated land with



residential or arable land This cultivated land does not have any vegetation cover during spring periods so it turns into a source of dust particles.

(iii) The multivariate analysis further confirmed the association between three types of dust storm frequency, meteorological factors and the NDVI. High loadings of dust storm frequency, wind speed, precipitation and NDVI on a PC indicate that the increased precipitation and NDVI will decrease dust storm frequency and increased wind speed will increase dust storm frequency. PCA results however did not reveal a direct association between NDVI and various land use types changes which may be due to the fact that NDVI is a combined indicator of various land use types. These land use types might have compensatory changes hence were not reflected in this combined indicator.

(iv) The results of this study also confirmed that dust storm is the outcome of interactions between weather process and human activities. As humans have limited ability to control the weather, so protection and improvement of ecology must be the key strategies to minimize the risk of dust storm disasters. In addition, the rapid population growth has demolished vegetation cover and exposed new sand sources that have contributed to dust storm formation in south edge of Taklimakan desert.

*Disclaimer* : The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

#### References

- Aili, A. and Kim Oanh, N. T., 2015, "Effects of dust storm on public health in desert fringe area : Case study of northeast edge of Taklimakan desert", *Atmos. Poll. Res.*, **6**, 805-814.
- AQSIQ (Administration of Quality Supervision, Inspection and Quarantine) and NSC (National Standards Committee) of People's Republic of China, 2006, Dust storm weather classification criterion, Standard code : GBT 20480-2006. Beijing : China Standard Press, (P7).
- Chen, Y. N., Xu, C. C., Hao, X. M., Li, W. H., Chen, Y. P., Zhu, C. G. and Ye, Z. X., 2009, "Fifty year climate change and its effect on annual runoff in the Tarim River Basin, China. *Quarter. Int.*, **9**, 1-9.
- Cheng, H. X., Hu, L. Q. and Lin, Y. J., 2014, "Temporal and spatial distribution characteristics of hot and cold spots of sandstorm in Xinjiang in recent 50 years", *Journal of Arid Land Resources and Environment*, **28**, 100-104 (in Chinese).
- Fu, Q., Li, B., Hou, Y., Bi, X. and Zhang, X., 2017, "Effects of land use and climate change on ecosystem services in Central Asia's arid regions : a case study in Altay Prefecture, China", *Sci. Total Environ.*, 607-608, 633-646.
- Gao, W. D., Yuan, Y. J., Liu, Z. H. and Wei, W. S., 2008 "Status of dust sources and aerosol formatting condition analysis in Xinjiang", *Journal of Desert Research*, **28**, 968-973 (in Chinese).
- Ivits, E., Cherlet, M., Sommer, S. and Mehl, W., 2013, "Addressing the complexity in non-linear evolution of vegetation phenological change with time-series of remote sensing images", *Ecol. Indic.*, **26**, 49-60.
- Jiang, L., Xiao, Y., Rao, E., Wang, L. and Ouyang, Z., 2016, "Effects of land use and cover change (LUCC) on ecosystem sand fixing service in Inner Mongolia", *Acta Ecol. Sin.*, **36**, 3734-3747.
- Lai, X. Q., Qin, L. and Zhang, F. H., 2002, "The eco-agricultural construction of oases and its sustainable development in Xinjiang", *Chinese Journal of Eco-Agriculture*, **10**, 129-130 (in Chinese).
- Lei, J. and Zhang, X. L., 2005, "Structural Adjustment of Oasis Agriculture in Xinjiang", *Chinese Journal of Population, Resources and Environment*, **3**, 58-63 (in Chinese).
- Li, B. F., Zheng, J. and Shi, X., 2020, "Quantifying the impact of mountain precipitation on runoff in Hotan River, northwestern China", *Front. Earth Sci.* <https://doi.org/10.1007/s11707-019-0811-7>
- Liu, M. Z. and Wei, W. S., 2005, "Effects of climate change on the occurrence of dust storms in southern Xinjiang since recent 60 years", *Arid Land Geography*, **28**, 479-483 (in Chinese).
- Liu, X., Yin, Z. Y., Zhang, X. and Yang, X., 2004, "Analyses of the spring dust storm frequency of northern China in relation to antecedent and concurrent wind, precipitation, vegetation and soil moisture conditions", *J. Geophys.*, **4**, 105-109.
- Shao, S. Y., Han, Y., Qin, F. Q., Xu, M. M. and Zhao, Y. F., 2019, "Spatial and temporal properties of a winter dust event in North China", *City Environ. Interact.*, **4**, 100-125.
- Shen, L., Tian, M. and Gao, J., 2016, "Analysis on wind erosion and main factors in desertification control ecological function area of Hunshandake using the revised wind erosion equation model", *Res. Soil Water Conser.*, **23**, 90-97.
- Shi, Y. L., Wang, R. S., Fan, L. Y., Li, J. S. and Ye, D. F., 2010, "Analysis of Land use - change and its demographic factors in the Original-stream watershed of Tarim river based on GIS and statistics", *Procedia Environ. Sci.*, **2**, 175-184.
- Sruthi, S. and Mohammed, A., 2015, "Agricultural Drought Analysis Using the NDVI and Land Surface Temperature Data : a Case Study of Raichur District", *Aquatic Proc.*, **4**, 1258 -1264.
- Wang, R. X., Liu, B., Li, H. R., Zou, X. Y., Wang, J. P., Liu, W., Cheng, H., Kang, L. Q. and Zhang, C. L., 2017, "Variation of strong dust storm events in Northern China during 1978-2007", *Atmos. Res.*, **183**, 166-172.
- Xu, X. K., Levy, J. K., Lin, Z. H. and Chen, H., 2006, "An investigation of sand-dust storm events and land surface characteristics in China using NOAA NDVI data", *Global Planet. Change*, **52**, 182-196.
- Yan, L., Zhang, R. Q., Maituohuti, A. and Chen, W., 2016, "SHRIMP U-Pb zircon ages, mineral compositions and geochemistry of placer nephrite in the Yurungkash and Karakash River deposits, West Kunlun, Xinjiang, northwest China : Implication for a Magnesium Skarn", *Ore Geol. Rev.*, **72**, 699-727.
- Zaiontz, C., 2015, "Real Statistics Using Excel", [www.real-statistics.com](http://www.real-statistics.com).
- Zhang, H. Y., Fan, J. W., Cao, W. and Harris, W., 2018, "Response of wind erosion dynamics to climate change and human activity in Inner Mongolia, China during 1990 to 2015", *Sci. Total Environ.*, **639**, 1038-1050.
- Zhou, X., Yamaguchi, Y. and Arjasakusuma, S., 2018, "Distinguishing the vegetation dynamics induced by anthropogenic factors using vegetation optical depth and AVHRR NDVI : A cross-border study on the Mongolian plateau", *Sci. Total Environ.*, 616-617, 730-743.