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Aeolian dust movement and deposition under local atmospheric circulation in a desert-oasis transition zone of the northeastern Taklimakan desert

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ABSTRACT

Taklimakan Desert, in the northwest China, is one of the main sources of dust storms in the world. Frequent dust storms have seriously affected the ecological environment of surrounding oases. Quantification of dust deposition on the different underlying surface is vital to understand the local atmospheric cycling and its effect on movement of the dust particles in desert fringe areas. To examine the contribution of airflow from different direction to the dust deposition rate, the desert–oasis transition zone between the Korla oasis and the northeast edge of the Taklimakan desert is selected as the study area. 36 h backward trajectories of air masses arriving at the study site from 1st March to 31st May 2023, were determined by using the HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory Model) model. The trajectories were categorized by *k*-means clustering into 3 clusters, which show distinct features in terms of the trajectory origins and the entry direction to the site. Dust collection tank were placed on five underlying surfaces from south to north: shifting sand desert, semi-shifting sand desert, desert vegetation, shelter forestland and croplands at the height of 0.2 m, 0.5 m, and 1.5 m. At the each of height, four dust collection tanks were arranged to collect the dust from 4 directions. Results show that, air masses from the south with highest frequency (46 days) and highest dust storm occurrence (91.3 %) is the main contributor of dust particles to the study area. Dust deposition rate on different underlying surfaces showed a significant decreasing trend from the desert to oasis, and the dust deposition on all underlying surfaces decreased with the height. Dust deposition corresponding to the southward wind direction is the highest, and the amount of fine dust particles are increased with the height of the dust collection tank. The results of this study could be helpful to forecast the potential occurrence and mowing pathway of dust storms, which can provide the basis for mitigation of the negative effects on the environment.

1. Introduction

Atmospheric dust fall is a dust substance that naturally settles to the ground due to the influence of gravity by aerosol components suspended in the air (Palchan et al., 2013; Zhu et al., 2014). Dust particulates in the air can significantly alter the solar radiation reaching the ground, affect plant photosynthesis, and pose extremely serious potential hazards to human health (Karaca et al., 2009; Wang et al., 2016; Flores et al., 2017). In the context of specific regional climate systems, the occurrence of dust storm weather is mainly determined by the nature of the underlying surface, especially in desert fringe areas. The Taklimakan Desert in northwest China is the second large shifting-sand desert in the world. The total area of this desert is 337,000 km^2, and has always been considered as the major source region of dust storms in China (Liu et al., 2011; Aili et al., 2021). Most of the habitable oasis are located at the desert fringe areas. The Korla oasis in the northeast edge of Taklimakan desert are belongs to more fragile region due to affected by severe dust storm (Lai et al., 2002; Cheng et al., 2014a; Aili and Kim Oanh, 2015). As it is located between the Taklimakan Desert and Kurukkum Desert, frequent dust storms lead to the deterioration of the ecological environment of Korla City, annual average dust storm frequency is around 180 days (Zhu, 2007; Ma et al., 2020). Some related research work on the dust storms and dust deposition which are providing a basis and practical methods for preventing and controlling of dust storm effects have been conducted from various perspectives and some fruitful results were achieved (Okada and Kai, 2004; Kumar et al., 2008; Li et al., 2012). However, with the development of the economy, and the increase of population, it is difficult to reverse the situation of unreasonable utilization of land resources in a short period of time, resulting in degradation of vegetation and the expanding of dust sources. Moreover, the

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global warming background is conducive to the occurrence of dust storms.

Currently, some advanced research methods and measuring techniques are used to determine the movement of sand-dust particles. Mohsen and Mohammad presented an empirical model for monitoring dust deposition using multi-linear regression (MLR) and artificial neural networks (ANN) approaches and employed metrological parameters over the Isfahan province in central Iran, and confirmed that the obtained models can perfectly predict dust deposition (r 2 = 0.95 to 0.97) from visibility, only (Mohsen and Mohammad, 2022). The HYSPLIT model which is capable of identifying the source-receptor relationships over long distances of air pollutants, has already become the most widely applied tool. The sources, moving pathway and deposition of dust particles can be identified by using HYSPLIT trajectory model on the basis of monitoring data and trajectory information (Draxler and Hess, 1997; Man and Shih, 2001; Pongkiatkul and Oanh, 2007). Mohsen et al. numerically investigated the process of dust deposition on three different photovoltaic parking lot structures, including a mono-pitch canopy, a duo-pitch canopy, and a barrel arch canopy, and found that a slight variation of the tilt angle has no significant effect on the dust deposition, and there is no significant correlation between the dust particles size and the amount of dust deposition (Mohsen et al., 2023).

The existing relevant research mainly focuses on the observation and statistics of the local atmospheric environment and typical dust weather processes in a relatively short period of time. Burgan developed a statistical models on the basis of the comparison of the different ANN (FFBP, GRNN, and RBF) algorithms and multiple linear regression model to predict the daily stream flow in the Kocasu River in Turkey, and indicated that the ANN (artificial neural network) model is more efficient to study the meteorological events (Burgan, 2022). Zhao et al. observed and analyzed the annual atmospheric dust deposition in Hotan oasis, and found that the dust deposition showed a decreasing trend with the increasing altitude (Zhao et al., 2005). Guan et al. conducted a statistical analysis on the relationship between atmospheric dust fall and dust storm frequency, and indicated that the suspended dust is an important factor affecting the amount of dust fall (Guan et al., 2000). An et al. studied the protection effects of a desert–oasis ecotone in Dunhuang, Northwest China by using portable wind-monitoring system, fixed automatic weather-monitoring instrument, and eight-directional sand-collecting instrument and found that the desert–oasis ecotone can effectively reduce regional wind speed, sand-driving wind speed, drift potential, and wind-blown sand activity (An et al., 2023).Aili et al analyzed the origin and transport pathway of dust storm and its contribution to the particulate air pollutants in the northeast edge of Taklimakan desert, and indicated that, the composition of atmospheric pollutants is related to the movement pathway of dust storm (Aili et al., 2021). In previous research work, although the short-term dust fall and dust pollution weather in the Oasis areas around the Taklimakan desert were observed and statistically analyzed, but the research on the quantification of dust deposition rate under atmospheric circulation and the impact of different underlying surface to the dust deposition characteristics is still relatively weak.

The novelty of this paper are mainly reflected in the representativeness of the study area as well as the innovation in research content and entity. (1) The northeast edge of the Taklimakan Desert with its extremely arid climate condition is an ecological fragile region due to severe dust storm hazards (Aili and Kim Oanh, 2015). The desert-oasis transition zone is the connecting zone between oasis and desert ecosystems, and the stability of its ecosystem directly affects the evolutionary direction of oasis and desert. The frequent and intense wind and sand activities in our study area had caused significant threats to the oasis and promoted the spread of desertification due to the resulting in sand and dust deposition. Therefore, the regional characteristics of the study area is an important supplement to existing research. (2) Innovation in research content and entity. In our study, the field survey data and indoor experimental data are combined with the GDAS meteorological data, the Aeolian dust movement and dust deposition rate within the shifting sand desert, semi-shifting sand desert, desert vegetation and shelter forestland were comprehensively analyzed to reveal the protection effects of different underlying surface. Our research objects could be an important supplement to previous research and partly fills in the gap. To our best of knowledge, this is the first study to investigate the dust deposition in different underlying surface in this area. The pattern of Aeolian dust movement and deposition within this transition zone can intuitively reflect the effectiveness of regional desertification prevention and control. Therefore, a scientific and comprehensive understanding of the current situation of wind and sand disasters, their movement paths, and the protective effects of different underlying surface on the wind and sand movement at the regional scale can provide theoretical and technical guidance for the research and management of wind and sand prevention in arid areas.

2. Materials and methods

2.1. Site selection

The Korla oasis is selected as the study area. This oasis is located at the northeast edge of Taklimakan desert and the northwest edge of Kurukkum desert. Due to being surrounded by mountains to the north and east, the cold air from the north and the humid air from the Yanji Basin are mechanically blocked, and strengthening the arid climate characteristics of the Korla Oasis. The climate condition of the study area belongs to a warm temperate continental arid climate, with a total sunshine duration of 2990 h, an average frost-free period of 210 days, an annual average temperature of 11.4 ℃, an annual average precipitation of 58.6 mm, and an annual maximum evaporation of 2788.2 mm (Cheng et al., 2014b; Li et al., 2019). The special geographical location between the two deserts leads to the frequent sand dust weather and the complex situation of local atmospheric circulation. Five types of underlying surface were selected from the desert-oasis transition zone of the south edge of the Korla oasis: namely: shifting sand desert, semi-shifting sand desert, desert vegetation, shelter forests and croplands (Fig. 1). The dust deposition rate on different underlying surface at different height and different direction were investigated and compared.

2.2. Data sources

Surface meteorological data including types of dust storm and wind speed data in the dusty season (from 1st of March to 31th of May) of 2023 were collected from the Korla Meteorological Bureau and the official website of the National Meteorological Administration (*http://cdc.cma.gov.cn*).Other meteorological data related to the air mass along with dust storm pathway were obtained by running a 36-hour backward trajectory model which is available at NOAA-ARL (National Oceanic and Atmospheric Administration: Air Resources Laboratory) website: *https://www.arl.noaa.gov/ready.html*.

Three types of dust storm weather, that is, suspended dust, blowing dust and sand storm were considered in this study, and were classified by using the criteria given by National Standard Committee (2006) into 3 intensity grade based on the severity. Among them, the suspended dust is the weaker type of dust storm which refers to the floating dust in the air under lower wind forces. The blowing dust is the medium severe type of dust weather with the horizontal visibility of 1–10 km. The sand storm is the most severe type of dust weather with the horizontal visibility is below 1 km and the wind speed is over 25 m/s (AQSIQ, 2006; Aili et al., 2022).

2.3. Methods

2.3.1. Classification of dust storm transport pathway

Total of 92 days in the dusty season of 2023 were selected for the HYSPLIT model analysis. The 36 h of backward trajectories of air mass

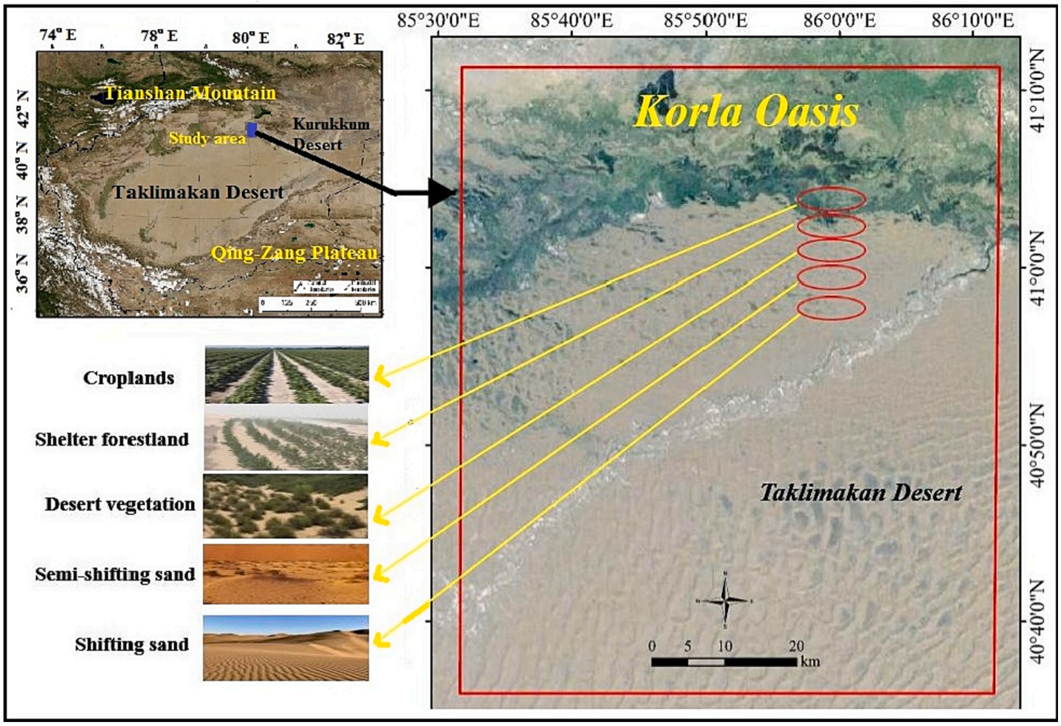

Fig. 1. Study area and surrounding environment.

were obtained by running the HYSPLIT model for each of the selected days. The starting point of the trajectory is 41.05°N, 85.90°E (south edge of Korla oasis), the starting time is 10:00 UTC (Universal Coordinated Time) each day. Considering the topographic constraint of Taklimakan Desert and surrounding areas, as well as the friction effects of the surface, the height of air masses at arriving point was fixed at 500 m above ground level (AGL). The "model vertical velocity option" was used for running the HYSPLIT model because of the meteorological variables were included in this option. The air mass trajectories were classified by using the *k-means* clustering technique (SPSS 21) on the basis of meteorological variables including ambient temperature (K), potential temperature (K), daily rainfall (mm/day), mixing layer depth (m), relative humidity (RH, %), solar radiation flux (W/m^2) and wind speed (m/s) measured at the arriving location. The coordinates of air mass backward trajectories include latitudes, longitudes and altitude of the air masses at 4 points on a trajectory: 9 h, 18 h, 27 h, and 36 h. Using k-means clustering, dataset can be divided into a certain number of homogeneous clusters (k).The cluster membership can be determined based on the distance between the data point and the kth centroids (Draxler et al., 2001; Hesam and Mohsen, 2019). The concentration of air pollutants corresponding to each clusters is also obtained by using cluster analysis.

2.3.2. *Observation and measurement of dust deposition*

Five observation section were selected from the desert- oasis transition zone in the southern part of Korla Oasis. These sections were arranged on five underlying surfaces from south to north: shifting sand desert (S1), semi-shifting sand desert (S2), desert vegetation (S3), shelter forestland (S4) and croplands (S5). The distance from S1 to S2 is 28 km, from S2 to S3 is 12 km, from S3 to S4 is 12 km, and from S4 to S5 is 0.4 km. Plastic dust collection tank were used to collect dust. The dust collection tank was a cylindrical plastic tank with an inner diameter of 15 cm and a height of 30 cm. The height of the dust collection tanks arranged in each section are 0.2 m, 0.5 m, and 1.5 m. To reveal the impact of wind from different directions on dust deposition, the dust collection tanks were arranged in four directions: east, south, west, and north at each height. Thus, total of 12 dust collection tanks were arranged in each section. Dust samples from each of the dust collection tank were collected on the last day of each month and were taken back to the laboratory. The experiment was conducted in the Central Laboratory of Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences. The experimental process was carried out according to the national standard "Ambient air Determination of dust fall Gravimetric method".Firstly, impurities such as leaves, insects, and insect carcasses are removed from the sample, and then dust samples dried at 105℃. An electronic balance with an accuracy of one thousandth is used to calculate the amount of collected dust. The dust deposition is calculated using the following formula:

$$M = W/\pi R^2$$

In the formula, M is the dust deposition in a month (g/m^2 • mon); W is the net weight of dust received in the dust collection cylinder (g); R is the radius of the dust collector cylinder port (cm). The methodological framework of this study is shown in the Fig. 2 (Fig. 2).

3. Results and discussions

3.1. *Classification of dust storm pathway in study area*

Total of 92 days were extracted from 1st March to 31st May in 2023 for dust storm classification. Among them, suspended dust weather occurred on 58 d, blowing dust weather occurred on10 d, sand storm weather occurred on 5 d, while other 27 d were non-dusty days.

The 36 h of HYSPLIT backward trajectories which show the origin and pathways of the air masses arriving at the ending point were obtained for 92 d. Based on the trajectory data obtained by using HYSPLIT model, air mass trajectories arriving at the study site were classified into 3 clusters by using k-means clustering technique. These clusters has different origins and the entry direction to the study area (Fig. 3).

It can be seen from the Fig. 3 that, the length, shape, vertical position and the origins of the 36 h back trajectories of 3 clusters are quite different.

(1) *Cluster 1: Northwest category.*

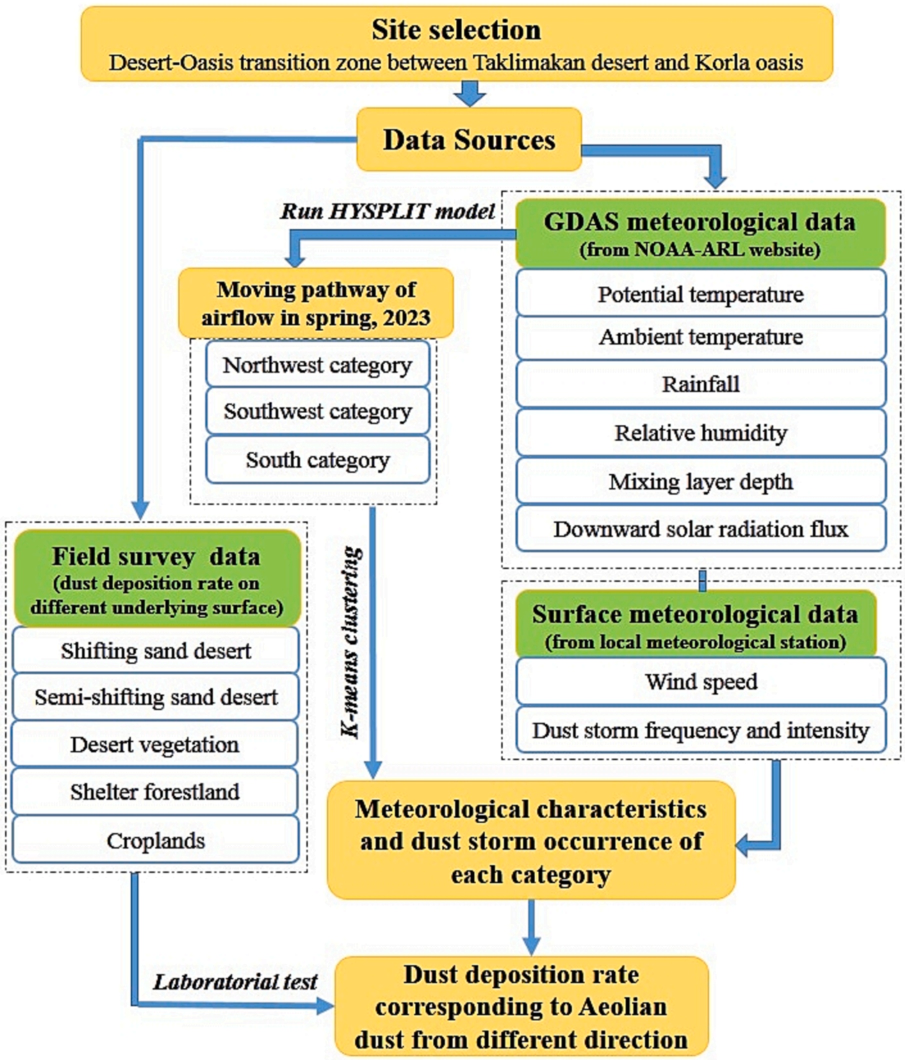

Fig. 2. Methodological framework of the study.

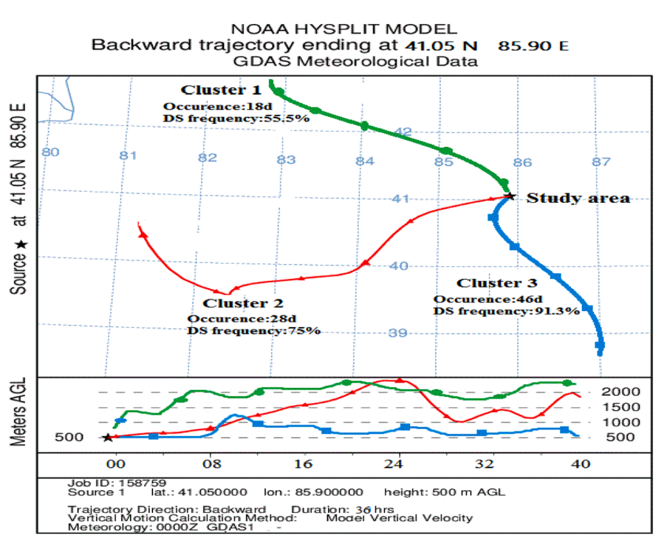

Fig. 3. 36 h of backward trajectory and vertical movement of dust storm arriving at study area.

Air masses of this cluster originate from the south slope of the Tianshan Mountain at an average altitude of 2200 m (Fig. 3), and move southeast direction through Cholkum desert, then turn to the south and finally arrive at the study site from the northwest. This cluster occurs with the lowest frequency of all clusters, it was observed on 18 days out of 92 total days of dusty season, the main dust weather types is suspended dust (9 d) and non-dusty day (8 d). It has a longer pathway above the desert vegetation areas between the Cholkum desert and the oasis.

(2) *Cluster 2: Southwest category*.

Air mass within this cluster starts from the middle-west part of the Cholkum desert with higher altitude (1760 m, Fig. 3) and moves southward through the desert and turn to northeast, finally arrive at study site from the west direction. Number of the trajectory within this cluster is 28 d, and accounts for 28.4 % of the examined days. The mowing speed of this cluster is the slowest with the average wind speed is 2.3 m/s among all clusters of air masses (Table 1). Unlike with the cluster 1, it has a longer pathway above the desert areas.

(3) *Cluster 3: South category*.

Air masses in this cluster stars from the middle part of Taklimakan desert with lowest altitude (>600 m) and moves northward go through

Table 1
Frequency and meteorological characteristics of dust storm from different pathway and air pollutant's concentrations.

Parameters		Cluster 1 (Northwest category)	Cluster 2 (Southwest category)	Cluster 3 (South category)
Dust storm frequency	Total frequency (d)	18	28	46
	Suspended dust (d)	9	16	33
	Blowing dust (d)	1	3	6
	Sand storm (d)	0	2	3
	Non-dusty days (d)	8	7	4
Meteorological conditions	Potential temperature (K)	281 ± 23.2	287.3 ± 24.7	292 ± 25.3
	Ambient temperature (K)	266 ± 0.11	269 ± 12	279 ± 12
	Rainfall (mm / day)	0.54	0.22	0.18
	Relative humidity (%)	29 ± 1.4	27 ± 2.0	21 ± 3.1
	Mixing layer depth (m)	1338 ± 109	1749 ± 152	1841 ± 234
	Downward solar radiation flux (W / m^2)	436 ± 47	557 ± 49	592 ± 43
	Wind speed (m/s)	2.6 ± 0.4	2.3 ± 0.2	2.9 ± 0.7

the northeast edge of Taklimakan desert and then arrive at study site from the south direction (Fig. 3). The occurrence frequency of this cluster is the highest among the 3 clusters (46 days or 50 %). This air mass type can be characterized by hot and dry air mass with the highest ambient temperature of 279 K, lowest rainfall (0.18 mm/day) and lowest relative humidity (21.3 %) (Table 1). The wind speed is the highest (2.9 m/s). The longer pathway above the desert and the high speed movement of the air mass determines the higher frequency of dust storm weather in this cluster. The occurrence frequency, meteorological characteristics and air pollutant's concentration within each clusters are presents in Table 1.

3.2. Dust deposition at different heights of different underlying surfaces

The spatial variation of dust deposition rate reflects the characteristics of wind sand transport on different underlying surfaces, and also reflects the windbreak and sand fixation effect of different underlying surfaces in the desert - oasis transition zone. In this study, we observed the dust deposition rate at different height of different underlying surfaces from March to May, and found a significant decreasing trend in dust deposition from south (desert) to the north (oasis) with following order: shifting sand desert > semi shifting sand desert > desert vegetation > shelter forestland > croplands (Fig. 4).

In April, due to the frequent occurrence of strong winds, the dust deposition at all three heights showed a significant increasing trend. At the same time, the dust deposition on all underlying surfaces decreased with the height. In April, the dust deposition in the shifting sand desert at a height of 0.2 m was 1082.6 g/m2, while in the croplands the dust deposition was only 456.1 g/m2. In the same period, the dust deposition in the shifting sand desert at a height of 0.5 m was 991.2 g/m2, while in the croplands was only 441.4 g/m2. Similar variation trends were observed at the height of 1.5 m, indicating that vegetation coverage can effectively reduce the movement of the dust particles. By comparing the average dust deposition at three different heights of 0.2 m, 0.5 m, and 1.5 m on each underlying surface, we found the significant differences in dust deposition at different heights. As the height increased, the dust deposition showed a significant downward trend, indicating that the wind sand flow in the study area showed a significant gradient change in vertical height. On the contrary, in desert vegetation areas, during the most severe dust storms period (April), dust deposition increased with height. The reason for this is that, in the section of desert vegetation, the vegetation coverage is increased, but the vegetation height is generally low. The surface layer is more stable than the shifting sand desert and semi shifting sand desert, dust emission from the ground is relatively small. In addition, the mechanical blocking effect of lower vegetation at a height of 0.2 m results in relatively small amount of dust deposition. As the height increased to 0.5 m and 1.5 m, due to the lower growth of vegetation (<0.4 m), the mechanical blocking effect of vegetation weakens, resulting in an increase in dust deposition with the height. In the section of shelf forestland and croplands, as the height increases, the dust deposition shows a decreasing trend, but the decreasing trend is not significant, with an average variation of 58.3 g/m^2.

Regarding the surface conditions of different underlying surfaces, the surface soil tended to be thicker in shifting sand desert and semi shifting sand desert. The surface dust was easy to be blown into the air in these areas. So these areas turned into the dust source. However, the surface soil tended to be refined in the desert vegetation area and shelter forestland. The vegetation can reduce the wind speed and restrain the sand and dust. The shelter forest system can also intercept and degrade the sand and dust. Hence, the surface dust cannot easily blown into the air.

3.3. Contribution of wind from different directions to dust deposition

Since the study area is located between Tianshan Mountain and the

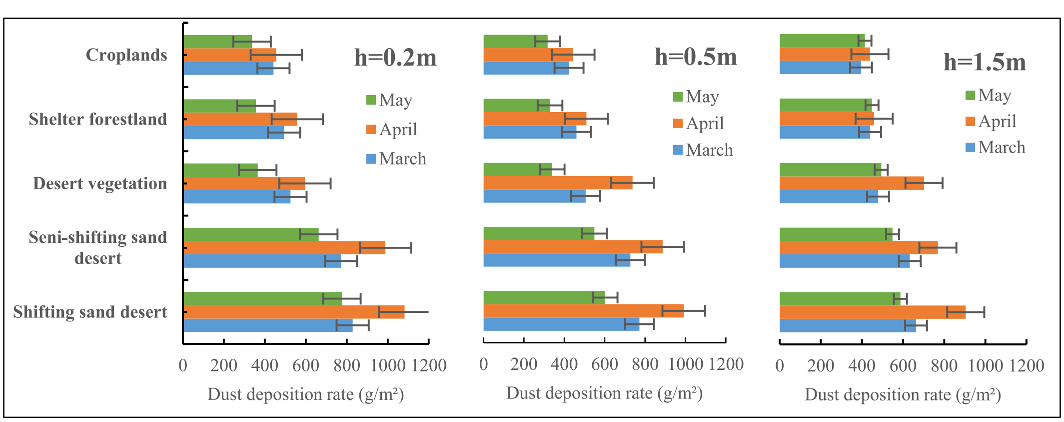

Fig. 4. Dust deposition at different heights of different underlying surfaces.

Taklimakan Desert, the local atmospheric circulation is complicated due to the pressure gradient between mountains and deserts. During the field investigation, we found that the wind direction in the study area often varies with different underlying surface conditions. According to the HYSPLIT backward trajectory model and surface meteorological monitoring data, the main wind directions in the study area are NW, WS, and ES directions. Due to the mountainous area to the north, the oasis area to the east, and the desert to the south and southwest, although the study area is affected by winds from different directions, but there are remarkable differences in the contribution of wind from different direction to dust deposition. The total amount of dust deposition from different directions on different underlying surfaces from March to May are compared, the results are presented at the Fig. 5.

It can be seen from the Fig. 5 that, at all observation sections, the total amount of dust deposition from the south direction in the shifting sand desert is 2616.6 g/m^2, and decreased towards to the north (oasis) direction, and reduced to 1762.5 g/m^2, in the croplands. Based on the results of our backward trajectory model, during the study period, the airflow frequency from south to north is the highest, which is 46 days, the frequency of dust storms in this airflow is 91.3 %. Higher frequency of airflow and the dust storms from south to north direction determined the higher dust deposition rate corresponding to this direction. Furthermore, the southern part of the study area is the Taklimakan desert, the loose sand and dust particles from the surface can easily be taken off into the air by the wind, resulting in more dust deposition from south direction than in other directions. In addition to the wind from the south, the contribution of the wind from west to the east to the dust deposition is also relatively high. This result further confirms the reliability of the results of our backward trajectory model.

Cluster 1 and cluster 2 come from the northwest and southwest directions, and the frequency of airflow and the incidence of dust storms in these two directions are not higher than those in Cluster 3. Especially, the airflow within the cluster 2 from the southwest is the slowest with the lowest average wind speed of 2.3 ± 0.2 m/s among the three clusters. However, the dust deposition corresponding to west direction is higher than that of north and east direction. Analyzing the reasons of this result, our study area is contacted with the Cholkum desert which is dominated by semi fixed sand dunes in the west, hence, even weaker wind from the west and southwest direction can also blow the dust particles from the desert into the air, and causes the higher contribution to the dust deposition.

The airflow from north to south and from east to west both pass through the oasis area, but during the dust collection, it was found that there was also some amount of dust fall corresponding to these two directions. For example, in shifting sand desert, the dust deposition from the north and east are 1806.3 g/m^2 and 1491.6 g/m^2, respectively, while in the croplands, the dust deposition from these two directions are 1205.1 g/m^2 and 1105.5 g/m^2. Although in the results of the backward trajectory model, the frequency of the air flow from north to south is low (18 days only), or even the air flow from east to west is not detected, but the local atmospheric circulation is complex, and the air flow direction and wind speed will often be changed in short period. Moreover, our backward trajectory model is the long distance movement of the air flow within 36 h, and there still existing certain gap between results of the trajectory model and the short range movement path of the air flow. Furthermore, the above ground level (AGL) at the ending point of backward trajectory model is 500 m, and the height of dust collection experiment are 0.2 m, 0.5 m and 1.5 m, the direction of air flow at a height of 500 m and the near ground layer may not be exactly the same. Therefore, there is a significant difference in the frequency of airflow from different directions as the demonstrated by the backward trajectory model, and even the frequency of airflow from the eastern direction is zero. However, the difference in dust deposition corresponding to different directions are not as significant. Overall, the frequency of airflow from different directions obtained by the trajectory model is basically consistent with the amount of dust deposition in the corresponding direction.

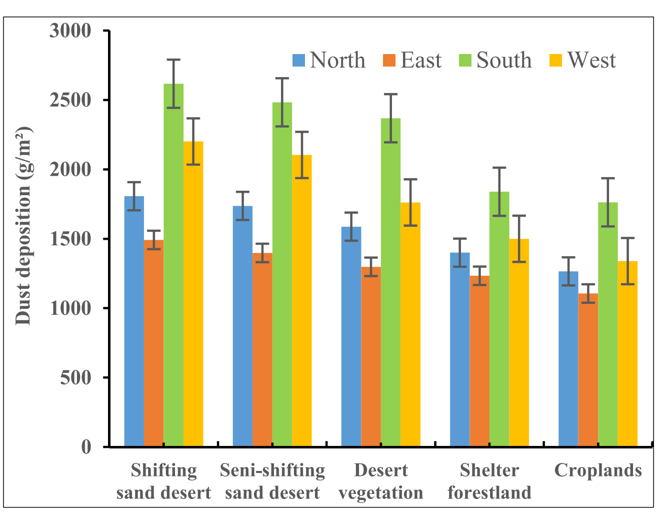

Fig. 5. Total amount of dust deposition from March to May under the influence of the winds from different direction.

3.4. Distribution of particle size in different height

In this study, dust particle size on the five types of underlying surfaces at the heights of 0.2 m, 0.5 m, and 1.5 m were analyzed and compared. The results are shown in Table 2.

It can be seen from the Table 2 that the particle size of dust at a height of 0.2 m is mainly within the range of 0.001–1 mm, coarse particles with particle sizes of 0.1–0.25 mm accounting for 82.8 % of the total sand deposition, followed by particles with particle sizes of 0.05–0.1 mm, accounting for 9.3 % of the total, and particles with particle sizes of 0.005–0.01 mm accounting for 2.6 % of the total. The content of coarse sand is relatively low, and the dust content of particles with particle sizes of 0.25–0.5 mm and 0.5–1 mm are 0.6 % and 0.5 %, respectively.

At the heights of 0.5 m and 1.5 m, the amount of coarse dust with a particle size greater than 0.5 mm is 0, and particle sizes of dust range from 0.01 to 0.25 mm. At height of 0.5 m, the amount of particles with a particle size between 0.05 and 0.1 mm accounts for 34.6 % of the total amount, followed by particles with a particle size range of 0.01 to 0.05 mm, accounting for 28.7 % of the total amount. The weight of sand and dust with a particle size range of 0.01 to 0.25 mm accounts for 84.6 %. At a height of 1.5 m, the amount of dust particles with particle sizes ranging from 0.01 to 0.25 mm accounts for 85.6 % of the total amount. Among them, the amount of particles with a particle size range of 0.05 to 0.1 mm is the highest, accounting for 43.8 % of the total, followed by 0.1 to 0.25 mm, accounting for 22.9 % of the total. The amount of particles with a particle size less than 0.01 mm accounts for 14.2 % of the total, and the particle amount in this range is significantly higher than that at the heights of 0.2 m and 0.5 m.

In the source region of dust storm, under the influence of wind power, especially in high wind speeds, coarse sand on the ground surface can jump to a height of several tens of centimeters above, while fine sand can enter higher heights. The results of the particle size distribution of sand and dust at different heights also indicates that as the height of the dust collection tank increased, the amount of fine sand particles are also increased. The dust particles collected at a height of 0.2 m above the ground are relatively coarse, indicating that the collected dust is mainly local sand. At heights of 0.5 m and 1.5 m, the sand particle size gradually decreases, mainly collecting silt and sticky sand, which is consistent with the vertical distribution characteristics of sand and dust in the atmosphere. The higher the height, the smaller the particle size. The collected silt dust particles at a higher AGL are not only comes from the

Table 2
Distribution of particle size in different height.

Height	Particles size (mm)							
	< 0.001	0.001–0.005	0.005–0.01	0.01–0.05	0.05–0.1	0.1–0.25	0.25–0.5	0.5–1
0.2 m	0.6 %	2.1 %	2.6 %	1.3 %	9.3 %	82.8 %	1.1 %	0.2 %
0.5 m	4.3 %	4.9 %	3.3 %	28.7 %	34.6 %	21.3 %	2.9 %	0 %
1.5 m	6.6 %	3.5 %	4.1 %	18.9 %	43.8 %	22.9 %	0.2 %	0 %

local sand sources, but may also be partially exogenous sand and dust substances. During the occurrence of dust storms, larger particles generally come from the nearby areas due to their own weight, while smaller particles will continue to move forward with the sand flow and settle further away.

4. Discussion

In the context of a specific regional climate system, the occurrence and duration of dust storm weather are mainly determined by the nature of the underlying surface, especially in the desert- oasis transition zone. There are feedback relationships between the dust storm occurrence and the variation of underlying surface (Zhang et al., 1997; Arimoto, 2001; Uno et al., 2009; Wang et al., 2017). Exposed desert sandy soil often becomes the origin of dust storms. Changes in vegetation cover can also cause the changes in the roughness of the underlying surface, leading to the occurrence of dust storms (Zu et al., 2008; Wang et al., 2019). On the other hand, vegetation changes will also have an impact on soil structure. When vegetation coverage increases, the adhesion between soil particles will increase significantly, thereby reducing the occurrence probability and intensity of dust storms. The impact of changes in the underlying surface on the local microclimate and dust storm occurrence are illustrated at the Fig. 6 (Fig. 6).

Sand source is one of the ultimate conditions for the occurrence of dust storm weather, and the spatial variation of dust deposition rate reflects the characteristics of dust transport on different underlying surfaces in the oasis desert transition zone. The results of this study on the variation of dust deposition with different height and different direction further confirmed the relationships between underlying surface, dust storm occurrence and its movement pathway.

There is a strong correlation between climate change and underlying surface change at both local and global scales (Zhao et al., 2006; Flood et al., 2015). Domestic scholars analyzed the distribution characteristics of aerodynamic parameters at different heights on the different underlying surface, and obtained the distribution laws of sand and dust particles on different underlying surfaces and at different heights. Mao Donglei et al. studied the characteristics of particle size distribution, difference of sand flux and evaluation of vegetation protection effect under different underlying surface conditions by arranging meteorological stations on different underlying surfaces in the desert-oasis transition zone near the Cele county, observing wind conditions and sand transport potential at heights of 2 m and 10 m, and combining particle size analysis of surface sediment deposition, and found the significant correlation between the movement distance of particles and particle size (Mao et al., 2013). For the study of dust transport flux, a large number of observation and simulation studies have been

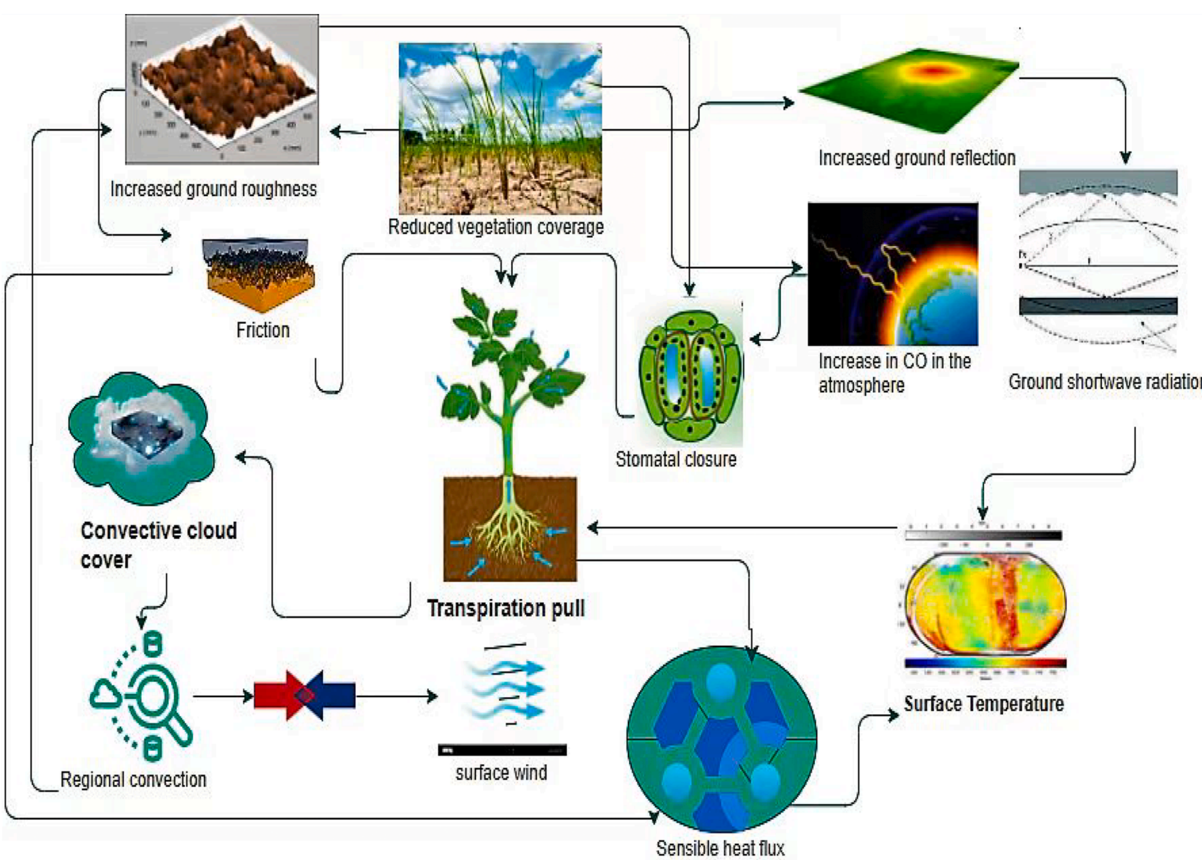

Fig. 6. Impact of underlying surface changes on local microclimate and dust storm weather.

conducted both domestically and internationally, mainly studying the trend of dust transport under different underlying surface conditions and the variation patterns of dust transport at different heights. Zhang Hua et al. studied the vegetation protection benefits under different vegetation coverage in Horqin Sandy Land, and found that, with the increase of underlying surface roughness, the maximum friction wind speed of grassland, the maximum sand blowing wind speed, the surface sand flux, and the surface wind speed all changed (Zhang et al., 2004). Hu et al., analyzed the sandblasting dust particles, which were mobilized using a chamber with surface soils of sand dunes in the Taklimakan desert to statistically quantify the shape and mineralogical composition of dust particles, and found that the size distribution of the particles shows a mode range of 0.5–0.7 μm for dust particles from sand dunes, and for particles from the Gobi soils, the mode is approximately 1.0 μm (Hu et al., 2022).

The movement and deposition of dust is a natural process with the complexity and comprehensiveness of natural processes, which puts forward high requirements for research methods and data acquisition. Results of our study on the dust deposition on different underlying surfaces at different heights are consistent with previous research results. The shifting sand desert and semi shifting sand desert are considered as the material basis for the occurrence of dust storms. Once there is sufficient wind speed, sand and dust particles are easily blown into the air, increasing the amount of dust deposition at the monitoring section. In desert vegetation, shelter forestland and croplands, the vegetation has a mechanical blocking effect on the movement of sand and dust particles, resulting in the reduction of dust deposition from desert to oasis. Under the action of gravity, the particle size of dust were decreased with the increase of ground height. Desert- oases transition zone, as an important barrier for ecological protection of oases in arid areas, enormous of engineering measures and research work has been carried out to protect its vulnerable ecosystem. In this study, considering the unique regional characteristics of the study area, the dust deposition rate on different underlying surfaces corresponding to aeolian dust from different direction were examined by using field monitoring data and indoor experimental data along with the trajectory model. The method used in this study is simple and creative, can be applied to other regions of the world, and especially in areas similar to the study area, but this doesn't guarantee it can accurately estimate the dust deposition all over the world.

5. Conclusion

(1) HYSPLIT backward trajectory model and the *k*-means clustering method classified the movement pathway of air masses in the dusty season of the study area into 3 clusters which have different origins and the entry direction to the study site. Among them, air masses within the cluster 3 (South category) has a longer pathway above the desert and the movement speed of the air mass is high. Therefore, the air flow from the south with highest frequency (46 days) and highest dust storm occurrence (91.3 %) become the main contributor of dust particles to the study area.

(2) Dust deposition rate on different underlying surfaces showed a significant decreasing trend with following order: shifting sand desert > semi shifting sand desert > desert vegetation > shelter forestland > croplands, indicating that the increased vegetation coverage can effectively reduce the movement of Aeolian dust. At the same time, the dust deposition on all underlying surfaces decreased with the height.

(3) The local atmospheric circulation around the study area is complicated due to the pressure gradient between mountains and deserts. Dust deposition corresponding to the southward wind direction is the highest, followed by to the westward wind direction because of the study area is directly contact with the desert on the south and the west.

(4) The amount of fine dust particles are increased with the height of the dust collection tank. At a height of 0.2 m, dust particles are composed mainly of coarse particles (82.8 %) with the sizes of 0.1–0.25 mm, while at heights of 0.5 m and 1.5 m, the dust particle size gradually decreased. Further research will be conducted by analyzing the multivariate relationships between gravity, wind velocity and dust particle size to reveal the mechanism of Aeolian dust movement.

Author contributions

Aishajiang Aili and Xu Hailiang formulated the designed the experiments. Xu Qiao and Liu Kun contributed to data interpretation and validation work.

CRediT authorship contribution statement

Aishajiang Aili: Conceptualization, Methodology, Formal analysis. **Hailiang Xu:** Conceptualization, Methodology, Formal analysis. **Qiao Xu:** Data curation, Software. **Kun Liu:** Data curation, Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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