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Effects of Soil Moisture Content on Dust Sources in Disturbed and Pseudo Undisturbed Soil in Southeastern Ahvaz

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Abstract
This research conducted various experiments using a wind tunnel on soil samples from the most critical parts of dust sources in southeastern of Ahvaz. The main goal of this study is to show the effect of moisture on the movement of soil particles in the dust centers. The laboratory work was carried out in two parts: a: Addition of water to completely disturbed soil surface (wetting in the bag) b: Addition of water to soil layers of samples wetting that was named pseudo undisturbed soil.

The results showed that dust generation under natural conditions (dry soils) in a laboratory wind tunnel will be 53 times more than the pseudo undisturbed soils with moisture content of 2-4% in volume. Moreover, soils with moisture contents of 5-8 and 10-12% do not differ significantly from those with 2-4% moisture content in preventing dust generation. If soil surface is disturbed after it is provided with adequate moisture, not only will dust generation not decrease compared to the case when the soil surface was dry but it will also increase by 25 percent. The practical point of this study is that in the study area, increasing soil moisture between 2 to 4% can greatly reduce the formation of dust.

Keywords: Erosion, Dust, Soil Moisture Content, Granulation, Wind Tunnel, Soil Stabilization.
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Introduction

Dust in soil erosion usually refers to particles with diameters of silt or clay particles (< 63μm) (Ekhtesasi and Jahanbakhsh, 2015). Dust consists of fine mineral particles that are emitted into the atmosphere when wind blows. In meteorology, haze refers to fine atmospheric particles with high concentrations that reduce horizontal visibility.

In nature, wind erosion results in three types of movement by soil particles depending on wind speed: by saltation, surface creep, and suspension. Various factors influence soil erodibility including soil texture, cohesion of soil particles, soil structure and soil organic matter, particle shape and moisture. This study emphasized on soil moisture as one of the factors that have the greatest influence on dust sources. Soil moisture is the most important factor influencing wind erosion, and soils are susceptible to wind erosion when they are dry. Wind easily transports dry soil particles (Rafahi, 2012).

Dust, an important atmospheric pollutant, can also be troublesome for people living long distances from where it is generated. Causing or increasing incidence of respiratory diseases is among the most important impacts of dust storm occurrence (Hojati et al., 2012). Ostro et al. (1999) reported associations between PM10 and daily mortality in Coachella Valley east of Los Angeles. Kwon et al. (2001) stated that there was a significant relationship between weekly Asian dust storms and mortality resulting from cardiac, vascular, and respiratory diseases. Based on studies in Kermanshah province of Iran, there will be a 0.5% increase in the number of patients with respiratory diseases, almost a 1% rise in the number of people with heart diseases and nearly 0.3% higher mortality rate in heart patients with every 1% increase in air pollution caused by dust (Delangizan and Jafari Motlagh 2013). Goudarzi et al. (2015) estimated the burden of respiratory diseases caused by exposure to PM10 in Ahvaz city of Iran.

Khuzestan province in southwestern Iran is among the most important regions influenced by dust storms due to its dry climate and the numerous desert areas in its western and southern parts (Khosravi, 2010). During 2000-2015, there were 1507 recorded dust storm events in Khuzestan province 65% of which happened in cities of Ahvaz and Abadan. The reason for this could be their proximity to dust sources inside and outside of Iran (Nabavi et al., 2019). In their research, Mojiri et al (2015) reported that destruction of vegetation, drying up of the wetlands and uncontrolled water usage and conveys from the basins of the rivers flowing into the Khuzestan plain were the three main reasons for the growing number of dust sources in Khuzestan province. In a research, Sohrab Ghaedi (2015) investigated the trend of dust storm occurrence in Ahvaz, Abadan and Dezful. He reported that most of the dust storms at all three stations in these three cities happened in summer, especially in July. Using remote sensing images, Ziauddin Shoaei et al. (2015) studied the relationship between soil moisture content and dust storm occurrence in Ilam Province.

Rule No. 658 of the Management and Planning Organization (2014) states that wind erosion is one of the major dilemmas of the arid and semi-arid regions (Vice President for Strategic Planning and Oversight, 2014). Mark et al. were quoted as saying that the most important factors influencing the threshold friction required for particle movement were soil moisture, land surface roughness, vegetation cover, and extent of surface crusting (as mentioned in the report of Agricultural Research, Education and Extension Organization, Research Institute of Forests and Rangelands, 2017). Soil moisture increases soil threshold friction velocity because infiltration of soil capillary water causes particle cohesion. These researchers believe that particle transport by wind decreases when soil moisture content exceeds 4% of its weight. Nourzadeh et al. (2013) studied the effect of surface soil moisture (the top 3 cm of soil) on threshold friction velocity, the horizontal sediment flux, and dust concentration by using a wind tunnel on 11 soil samples near Ahvaz. Their results showed that 3% moisture content was the threshold at which above-ground dust concentration reached zero. Sirjani et al. (2019) conducted studies on soil samples in Fars province. By using a wind tunnel, they observed that there was a negative nonlinear relationship between the extent of wind erosion and soil characteristics including vegetation cover of the sand surface, mean soil particle diameter and weight, soil clay particles and soil moisture. The main goal of this study is to show the effect of moisture on the movement of soil particles in dust centers located in east of Ahvaz.

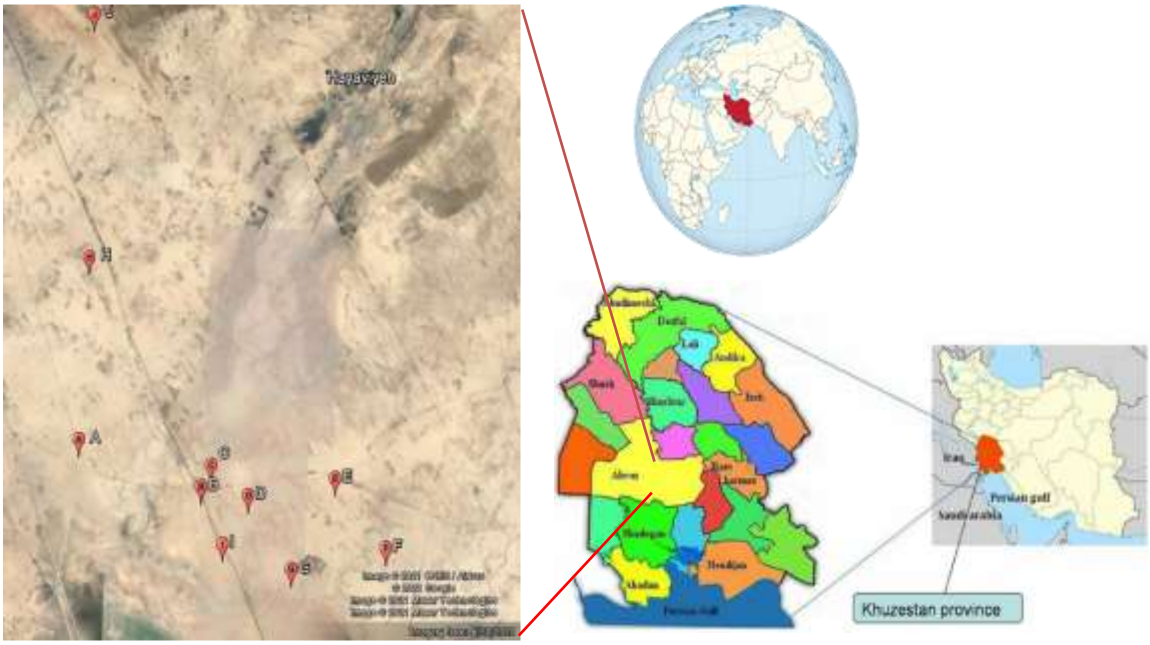
Materials and methods

Soil samples were taken from 10 critical dust sources in Khuzestan province called the dust generation centers of southeastern Ahvaz. Figure (1) shows the locations of the collected soil samples, which were named A, B, C, D, E, F, G, H, I, and J together with their coordinates.

A 9-m long laboratory wind tunnel having a square cross section (with the side of 70 cm) was used at the faculty of agriculture of Shahid Chamran University of Ahvaz

(Figure 2). A variable speed fan was employed to generate air flows at various velocities. The soil samples were taken at the depth of 5-10 cm, poured in 40-kg bags and transferred to the laboratory. Some of the soils were placed in test trays (50 cm long, 30 cm wide and 4 cm deep) to carry out the experiments (Figure 3). About 8 kg of the soil was used for each experiment. The surface of the soil in the test tray was flattened and the tray was weighed and placed in the wind tunnel for the experiment.

To reduce the impact of the airflow on the front edge of the tray and decrease the rotational flows, an upside down test tray was placed at the back of the test tray containing the soil level with the soil surface so that the velocity profile of the wind flow reach to the soil surface at the front of the tray would be developed as much as possible.



Zoom 39	A	B	C	D	E	F	G	H	I	J
E coordinate	300199	308087	308685	311099	316656	319975	313946	300670	309513	300724
N coordinate	3428136	3425602	3426835	3425157	3426219	3422301	3420996	3438505	3422355	3452370

Fig. 1- Locations of soil samples taken at dust sources in Ahvaz

a: The schematic of the wind tunnel B: Wind tunnel during the test

Fig. 2- Different views of wind tunnel

Fig. 3: Pseudo undisturbed and wetted soil sample

A LUTRON PMS714 soil moisture meter was used to determine volumetric soil moisture percentage.

This instrument can be employed to measure moisture content of soil and similar materials directly, very conveniently and as rapidly as possible. It can measure soil moisture content from 1 to 50% with a resolution of 0.1percent. Its probe total length is 220 mm (probe diameter 10 mm).

Water was added to the soil using two methods. In the first one, the soil was placed in a plastic bag and water was slowly added while the soil in the bag mixed. After the required moisture percentage was uniformly achieved, the disturbed soil was poured into the test trays, the tunnel experiment was performed, and the data were recorded. This experiment, called the disturbed state, was carried out for the A, B, C, D, E, F, G and H samples.

In the second method, the dry soil was poured into the trays in several layers and water was added for each one for the soil to have a largely uniform moisture content. In this case, the soil nearly formed like field situation when the required water will added to the entire soil. Following the addition of water, a plastic cover was put on the soil for the moisture to be uniform in all the layers and for the water to have the opportunity to move from layer to layer so as the entire soil had the same moisture content of interest. After almost 24 h, the soil sample was placed in the wind tunnel. Before performing the experiment, soil moisture content was measured at several different points. If the moisture content was in the desired range, the experiment would be carried out.

A laser diffraction particle size analyzer at the Faculty of Water Sciences Engineering in Shahid Chamran University of Ahvaz was used to measure particles size granulation of the collected soil samples.

Table (1) presents a summary of the statistical information of particles size of soil samples. Silt and clay particles constituted more than 50% of all the soil samples.

A CEL-712 Microdust Pro instrument was used to record generated dust concentration in mg/m^3. The air current carrying the dust enters the probe inlet and the concentration of the dust passing through it is recorded using laser light diffraction. During the experiment, the dust is collected in a special chamber to directly measure the mean dust concentration and to calibrate the laser diffraction prob. The instrument was set at 30 seconds to record dust concentrations so that it could automatically record the mean concentration of the passing dust every 30 seconds as a number. The instrument was placed on a stand so that the dust entered the instrument at a height of 10 cm from the tunnel floor. Since the height of the soil tray was 4 cm, its distance from the soil surface was about 6 cm. The instrument was installed in tunnel 10 cm downstream from the end of the test tray (Fig. 4).

A TES 1341 Hot-Wire anemometer was installed at the back of the test sample 10 cm above the soil sample to measure wind velocity. This instrument was also set to record wind velocity every 30 seconds. Therefore, dust concentration and wind velocity were measured every 30 seconds.

Table 1- Summary of the results obtained from soil particle size analysis

Soil sample	D (v, 0.1) mm	D (v, 0.5) mm	D (v, 0.9) mm
A	0.006	0.01	0.11
B	0.005	0.02	0.14
C	0.006	0.02	0.20
D	0.006	0.01	0.09
E	0.005	0.01	0.10
F	0.005	0.01	0.07
G	0.006	0.02	0.10
H	0.005	0.01	0.09
I	0.006	0.01	0.08
J	0.020	0.01	0.24

In the above table, the first column lists the names of the samples, the second column the size that 10% of the soil particles are smaller than, the third the size that 50% of the particles are smaller or larger than and the fourth the size that 50% of the soil particles are smaller than.

Fig. 4- Installment of the CEL-712 instrument in the wind tunnel

After placing the soil sample in the wind tunnel and installing the two mentioned instruments, the experiment began. The soil samples were naturally dry as they were collected in summer at the depths of 0-10 cm.

Following these preparations, the tunnel fan was switched on starting at low speed and reaching the maximum one that was set beforehand. At maximum speed, the motor's rpm usually reached its highest value after 100 seconds. Each experiment lasted 10 minutes and, as mentioned before, the experimental data were recorded every 30 s. At the end of the 10 min, measured using a chronometer, the motor was switched off and the measurements stopped. In each experiment, 20 data series on wind speed and dust concentration were obtained for each soil sample. In addition, the cumulative sample collected in the CEL-712 Microdust Pro instrument was poured in small plastic bags to be used for calibrating it and for performing particle size analysis. Table (2) lists the data on the samples and the results obtained by the CEL-712 Microdust Pro instrument.

Based on the mean recorded wind velocity and dust concentration for each experiment, the collected information and data were classified to perform the related analyses. Since there were 10 samples and hence10 experiments were conducted for each moisture percentage, and as two methods were used for wetting the soil samples and the experiments were replicated, altogether 70 experiments were carried out on the soil samples.

Table 2- Data obtained from the CEL-712 Microdust Pro instrument-results of the experiments on one of the samples

Firmware	Model	Serial No	Start	End	Profile Points	Interval S	Units	Average	Max	Max Time	Particulate Name
206017-06-00	CEL-712	5162128	08/05/2018 11:59	08/05/2018 12:09	21	30	mg/m3	421	497	08/05/2018 12:01	Default
					Time	Average					
					08/05/2018 12:00	408					
					08/05/2018 12:00	413					
					08/05/2018 12:01	419					
					08/05/2018 12:01	437					
					08/05/2018 12:02	428					
					08/05/2018 12:02	427					
					08/05/2018 12:03	422					
					08/05/2018 12:03	419					
					08/05/2018 12:04	421					
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					08/05/2018 12:05	419					
					08/05/2018 12:05	421					
					08/05/2018 12:06	422					
					08/05/2018 12:06	416					
					08/05/2018 12:07	414					
					08/05/2018 12:07	416					
					08/05/2018 12:08	419					
					08/05/2018 12:08	423					
					08/05/2018 12:09	423					
					08/05/2018 12:09	423					

In Table 2, rows 1 and 2 list the specifications of the CEL-712 Microdust Pro, the time the experiments were conducted, and the mean and highest values of the data during the experiments. The two columns below these 2 rows show the time dust concentration was measured and its mean concentration.

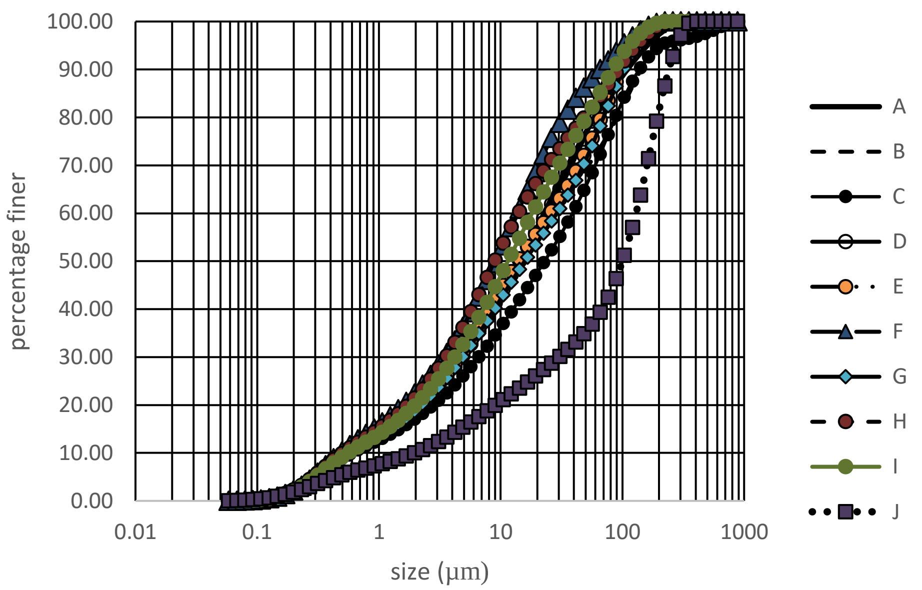

Fig.5- The diagram showing granulation of the tested soil samples

Analysis of the results

In Figure (5) the diagram of particles distribution (based on percent finer than) for all samples are shown. In this figure the x values are the size of the sample and y values are percent finer. It can be seen the particles distribution of all samples are nearly closed.

Based on the values obtained from the experiments on measuring dust concentrations at various moisture contents of the soil samples, the related tables were drawn up.

Table (3) presents the results of the various experiments including dust concentration at wind speeds and in different ranges of soil moisture content.

Table 3- Results of the measurements made for all the samples

	Natural Soil	Moisture 2-4%	Moisture 5-8%	Moisture 10-12%	disturbed soil, moisture 2-4%
Sampling location	Mean dust concentration mg/m^3	Mean dust concentration mg/m^3	Mean dust concentration mg/m^3	Mean dust concentration mg/m^3	Mean dust concentration mg/m^3
A	12915	303	276	184	18876
B	19001	421	372	272	36683
C	10703	281	373	257	8911
D	15553	257	386	206	12988
E	11172	191	420	180	16716
F	11124	203	207	185	14006
G	13691	202	372	178	15877
H	15860	368	183	350	14294
I	14339	242	416	195	
J	17516	226	416	244	

In Table 3, the first column lists the sampling location, the second column the mean concentration of the generated dust during the experiment on the sample in its natural dry state. Columns 3, 4 and 5 present the mean concentrations of the generated dust during the experiment at moisture contents 2-4, 5-8 and 10-12%, respectively and in the pseudo undisturbed state. Concentrations of the generated dust during the experiment on the disturbed sample with 2-4% moisture are written in column 6.

Table 4- Mean concentrations of dust generated (mg/m^3) in the reference point in the dry and wetted (2-4% moisture content) disturbed soil

Soil sample	A	B	C	D	E	F	G	H	Mean
Soil with almost 0% natural moisture	12915	19001	10703	15553	11172	11124	13691	15860	13752
Disturbed soil containing 2-4% moisture	18876	36683	8911	12988	16716	14006	15877	14294	17294

Based on the results concerning concentrations of the generated dust at various soil sample moisture content and under different conditions seen in table 3, the following conclusions can be drawn:

Base on the data of second and last column of the table when the disturbed and wetted soil samples were placed in the wind tunnel, erosion and dust generation increased compared to when the soil was naturally dry. Although the soil samples were wetted, soil aggregates could not be formed because the samples were disturbed. In addition, as the soil was simultaneously wetted and disturbed, its aggregates became smaller and the conditions were right for more dust generation. Furthermore, since the soil sample was in the wind tunnel for about 100 s and dried rapidly because of the blowing wind, dust generation was more intense. In fact, moisture did not enhance cohesion between soil particles and merely increased particle weight to a small extent compared to when the soil was dry. That is why little dust was generated at the beginning of the experiment but, after a short while, erosion and dust generation increased. Table (4) presents mean concentrations of generated dust in the experiments.

Table (4) shows that the mean concentration of generated dust in the reference point under the experimental conditions for the soil in the natural conditions of the study region was 13,752 mg/m^3. Under the same experimental conditions this mean concentration raise to 17, 294 mg/m^3 when the soil was wetted (2-4% moisture content). This increase indicated that disturbance of the soil in the region substantially decreased the effect of wetting the soil. Not only addition of water to the disturbed soil not decrease dust generation but it also increased it by 25%.

As shown in Table 4, in most cases dust generation increased (in some cases, as for sample B almost doubled) in the disturbed wetted soil compared to the natural almost dry soil.

Under laboratory conditions, the soil samples were wetted and given 24 h for the moisture to increase cohesion between soil particles. This 24 h opportunity given to the water added to the soil, and the fact that the soil was not disturbed, created conditions for the formation of a crust relatively resistant to erosion on the soil surface that substantially reduced dust generation. Presence of very cohesive soil particles and sufficient moisture in the soil led to the formation of crust. Figure (6) presents the amounts of dust generated under these conditions.

In the Figure (6) the dust concentration in the reference point and soil moisture percentage for the various pseudo undisturbed soil samples are shown. In this figure the y values are dust concentration in mg/m^3 .As shown in this figure, when the soil sample was not disturbed while it was wetted and after that, it contained 2-4% moisture and the mean concentration of the generated dust in the reference point in all the samples was 269 mg/m^3 whereas, in the natural conditions (soil moisture of 0%), the mean concentration of the generated dust for all the 10 soil samples in the reference point was 14,187 mg/m^3. In other words, dust generation under the natural conditions (dry soil) was 53 times more compared to the soil under natural conditions that was wetted to have 2-4% moisture without being disturbed. Under the same experimental conditions, when soil moisture content was raised to 5-8 and to 10-12%, the mean concentrations of the generated dust in the reference point were 342 and 225 mg/m^3, respectively. Comparison of the results of the experiment at different soil moisture contents revealed that raising soil moisture content from 2-4% to 5-8 or 10-12% did not considerably reduce dust generation. In the Figure (8) the effects of soil moisture on soil erosion in the various wetted soil samples and in dry soil are shown. In this figure the y values are dust concentration in mg/m^3.

As was mentioned in the introduction, we can compare the results of this research with those of similar ones such as the study by Nourzadeh et al. (2013) in 11 regions of west of Ahvaz. They reported that the threshold moisture content was 3 percent at which aboveground dust concentration declined to zero. Moreover, Sirjani et al. (2019) carried out a study in 20 regions in Fars province concerning the effects of soil moisture on soil erodibility. The results of the present research concerning increased soil moisture in pseudo undisturbed soil to 2-4% conform reasonably well to those of these two studies. No studies were found on simultaneously increasing soil moisture and disturbing it for comparing them with the present research.

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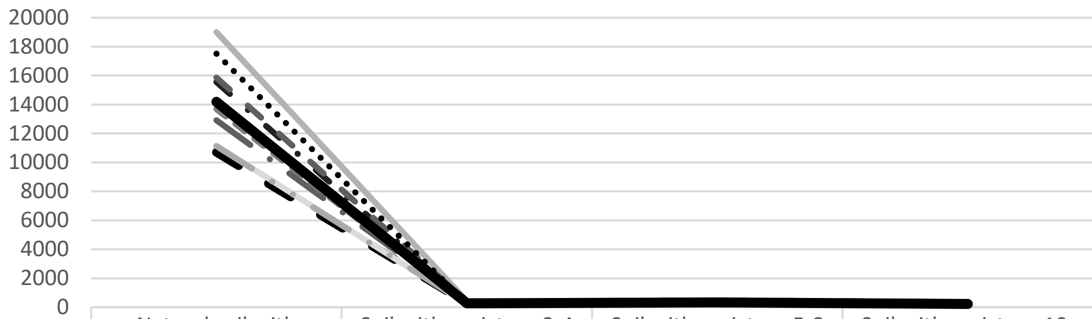
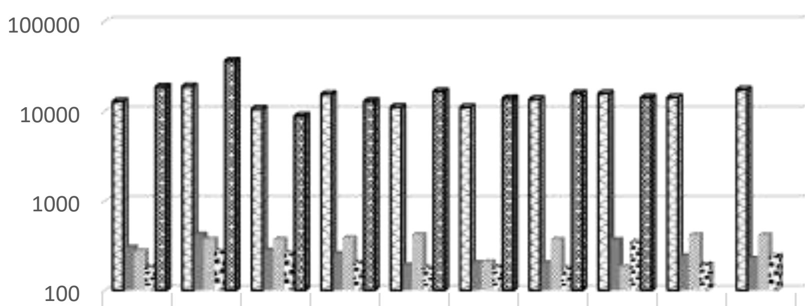


	Natural soil with moisture 0%	Soil with moisture 2-4 %	Soil with moisture 5-8 %	Soil with moisture 10-12 %
A	12915	303	276	184
B	19001	421	372	272
C	10703	281	373	257
D	15553	257	386	206
E	11172	191	420	180
F	11124	203	207	185
G	13691	202	372	178
H	15860	368	183	350
I	14339	242	416	195
J	17516	226	416	244
AVERAGE	14187	269	342	225

Fig. 6- The diagram comparing dust concentration in the reference point and soil moisture percentage for the various pseudo undisturbed soil samples



	A	B	C	D	E	F	G	H	I	J
Natural soil with moisture 0%	12915	19001	10703	15553	11172	11124	13691	15860	14339	17516
Soil with moisture 2-4 %	303	421	281	257	191	203	202	368	242	226
Soil with moisture 5-8 %	276	372	373	386	420	207	372	183	416	416
Soil with moisture 10-12 %	184	272	257	206	180	185	178	350	195	244
Soil with moisture 2-4 % mix	18876	36683	8911	12988	16716	14006	15877	14294		

Fig. 7- Bar graph showing dust concentration-soil moisture content under different soil conditions and various soil moisture contents

General conclusions

When fine-grained soils in the study region located at dust generation centers of southeast of Ahvaz with granule characteristics lose their texture due to drought or other reasons, they become potential centers of dust generation and usually generate amounts of dust when wind blows. Various methods are used to stabilize soils in order to mitigate the adverse effects of dust generation. One of them, which is totally natural and harmless to nature, is to wet the soil. Soil moisture can play its stabilizing role well if soil surface is not disturbed by practices such as plowing, vehicular traffic, destructive human activities, etc. In such soils, the most influential effect of soil moisture (which is also very important in soil stabilization) is the provision of the required conditions for the formation of soil aggregates on soil surface (which may also be accompanied by crusting). The best way to prevent soil erosion and hence dust generation is to provide such conditions. Disturbance of surface soil completely destroys the effect of raising its water content to 4% and increases dust generation by 25% compared to the natural conditions when the soil is not wetted.

Dust generation in the samples in the natural state (when the soil is dry) in the wind tunnel under laboratory conditions increased 53-fold compared to dust generation in the same soil if it was not disturbed and its moisture content was raised to 2-4%. The soils in the study region will be stabilized well and dust generation will be substantially reduced if they are not disturbed and their moisture content is raised to 2-4% or more.
Another important finding of the present study is that raising soil moisture content to more than 2-4% (and up to 12%) did not considerably decrease dust generation compared to when soil moisture content was 2-4%.

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