Potential of dust emission resources using small wind tunnel and GIS: case study of Bakhtegan playa, Iran

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Abstract

Determination of the high potential of dust emission is a requisite affair in the management of dusts emission and as well as avoiding its risks. Wind tunnel is among the most important approaches in the study of areas having high potential in emitting dusts. Extensive dried playas and desert areas require the making of low-cost, simple, and car-portable tunnels capable of presenting comparable data of various areas even supposing not having enough precision in the model of real wind motion. In this study, we first engaged in making a car-portable tunnel with a primarily semicircle section of 38 cm height, 50 cm diameter, and 110 cm length. A fan and key appliance with the ability to change speed were used along with a simple transformer launched with car battery. Then, concentration of the pm10 dusts was measured in the various wind speeds of 1, 2.5, 4, 5.5, and 7 m/s by the help of anemometer and digital equipments. The study of Bakhtegan playa was done, as the methodology of handling with this tunnel, in 35 positions, and zoning of the results was performed via ArcGIS software. Depending on the destructibility of the shell by wind, the areas under study were categorized as low potential (34%), medium potential (37%), and high potential (29%) in emitting dusts. The results of zoning spotted the high-potential areas on the map. The usage of small tunnels, as in the present model, may be applied in order for the low-cost and fast studies of vast areas to the purpose of playas management.

Keywords Dusts · Bakhtegan playa · Wind tunnel

Introduction

Sand storms and dusts are typical events in the desert and semi-desert areas. In recent years, the number and intensity of dust storms have increased significantly in Iran (Taghizadeh and Jabri 2018; Cao et al. 2015). Dust has adverse effects on human health and the environment and can even affect the quality of water resources (Jabri and Taghizadeh 2018). The first and fundamental stage in the control of environmental hazards is the detection of their origin and causes. This entails clear understanding of dusts' features, their emission mechanisms, and knowledge to decrease their resources (WHO 2005).

Climate changes, decrease in precipitation, and environmental alterations by humankind such as dam constructions, agricultural developments, and misuse of water and

soil resources yield increment in dust hot spots in vulnerable areas (Zafarnejad 2009; Tadele et al. 2017).

Playas are among the vulnerable regions which would gain the potential of becoming resources of dusts after being dried (Pelletier 2006). They contain extensive salt and clay sources which may alternatively be prone to erosion with wind, whence they turn out to be resources of dusts on a global scale (Baddock et al. 2009, 2016; Bullard et al. 2011; O'Brien and McKenna Neuman 2012).

Some of these substrates of dried lakes either are protected by evaporated salt shells, so preventing dusts extensively from emission (Baddock et al. 2011; King et al. 2011), or would become anti-wind protection agents by wet levels or temporary floods (Mahowald et al. 2003; Hahnenberger and Nicoll 2014; Nield et al. 2013). Shape and resistance of the crusts formed in different parts of a playa may vary dependent on the local conditions (Gillette et al. 2001).

Identification of the vulnerable spots in playas which have potential to become dust hot spots is of special interest for the prevention of destructive effects of dusts and deserts development. Among dust particles, those having

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diameters less than 10 μm (or pm_{10} particles) are of the most importance due to the possibility of suspension for a long time and transmission to long distances (Autrup 2010). The techniques for determining the emitted pm_{10} dusts lay still in the development stages (Roney and White 2006). One essential method of studying potential of dust emission is applying a wind tunnel, an approach indispensable in exploration of wind process and measuring the potential of soil emission (Houser and Nickling 2001). Depending on their applications, wind tunnels are categorized into groups: Large Wind Tunnels (LWTs), probably the best means to measure the particles though requiring 10–30 man hours to sample each station. Also, as for them, there is a need to carry a lot of equipment hindering movement in some stations. LWTs are occasionally set at the laboratory site, so the conditions of soil of the area should be provided there (Roney and White 2006). Small wind tunnels, albeit having less precision relative to the large ones, take less time to install in the sampling location.

Another tunnel type is dubbed as PI-SWIRL which is comparable with the small ones. Its installation takes 10 min per station. However, in this tunnel, instead of modeling the atmospheric flow, it is the shear stress which is modeled (King et al. 2011).

According to researchers, the items which should be taken into account in the construction of removable wind tunnels are:

1. The tunnels should be capable of generating a constant and measurable flow;
2. They should be easy to install and able to create wind flow similar to the atmosphere;
3. It should be durable;
4. It should be safe in use and transportation;
5. It should be capable to sample and represent erosion materials in the field level;
6. It should be portable;
7. It should be lightweight (Zing 1951).

The modeling of natural conditions using wind tunnels needs time and cost. The countries located in arid and desert areas always face with supply as well as expert human power problems in collecting data from dust hot spots and in discovering vulnerabilities. The scope of desert lands and dry playas in arid and semiarid regions located at low rainfall latitudes is very expanded, needing a host of sampling stations. The invention of simple and accessible equipment, although not able to model the real conditions, and often along with a lot of errors, it could carry out the study of more vast territories.

Regarding the great number of the stations, problems with handling electric generators, and saving install time, small wind tunnel was used in this investigation whose engine was

capable of working through a car battery, and which was portable by a small car. Its purpose, although not modeling of the real atmospheric flow, was to compare different levels of the playa from the viewpoint of particle emission potential. Most of the wind tunnel researches study the wind speed necessary for transmission and emission of particles (Roney and White 2004; Kurosaki and Mikami 2007), while in the present study, we have engaged typically in concentration changes in dusts with the fan speed, which is not necessarily the same as wind speed (due to similarity restrictions).

The GIS system has been frequently used in determining the critical points in the urban and industrial areas (Dehghani et al. 2015) and might be of great help in showing the hot spots of dust emission (Ochirkhuyag and Tsolmon 2008).

In this study, 35 stations of Bakhtegan playa located at S.E. of Iran were investigated, the sensitive and semi-sensitive areas were determined, and the information of the areas of the map concerning dust emission potential was presented through interpolation by the usage of ArcGIS.

Materials and methods

Situation of sampling stations

Located in southeast of Iran, the dried playa of Bakhtegan is situated east of Shiraz and at 25 km northwest of Neyriz. Being on salt dome, it has a high concentration of salt. Figure 1 shows an aerial picture of the playa Bakhtegan. The north and northwest parts of Bakhtegan playa are dehydrated in winter along with the contiguous Tashak playa due to possessing more moisture. In this study, the beaches which are dried up in recent years and which are more likely to be resources of dusts were sampled. Taking geographical coordinates and measuring dust particles was started from the distance between Bastram village and Tange Hana village and was continued along the south side of the playa, from southwest to west having the most dry-landing record. The points where measurements are carried out are specified in Fig. 1. Also, the investigation was done by the portable tunnel wind at the 35 points 3 to 5 km apart. The dust particles measurement was performed in the July to August time interval.

Features of portable wind tunnel

To measure dust emission potential as well as the concentration of the dusts resulting from different wind speeds, a “wind generator” apparatus was designed. Another purpose behind the creation of the device was to make comparison between different points of the playa by its being portable. So, neither dimensional simulation nor simulation of the

Fig. 1 Bakhtegan playa and sampling points

real wind speed with the speed of the wind generated by the fan was done.

The device is composed of three ingredients. The first part includes a single-phase blower fan with a voltage of 220, and 110 amperage, and 60 rpm having a rotor of diameter 30 cm. As regards the ability of the engine to rotate in two directions, the system could work both in suction and aeration conditions. According to the measurements by the digital anemometer, the minimum of wind speed inside the wind tunnel in the aeration case was 1 m/s, and the maximum was 7 m/s. The rotor was made from fiberglass and was resistant to the impacts of dust particles and to their morphological features. The blades made up 35° with the axial direction of rotation. A five-way key is set up on the fan engine to adjust the speed in five cases.

The second part contained an inlet opening with a primarily semicircle section of 38 cm height, 50 cm diameter, and 110 cm length. The material of the different parts was the galvanized iron.

The third ingredient consisted of a funnel compartment at the end of which a hole of 5 cm diameter is contrived. The dust particles arising from different wind speeds left from the hole out, and by using the portable device, the concentration of the particles as well as their volumes was calculated. A hole is applied at the ceiling of the wind tunnel with a distance of 30 cm from the inlet to set up the speedometer device at the 30 cm height from the bottom. Figure 2 shows a schema of the parts of the artificial wind appliance.

Fig. 2 Wind tunnel

Fig. 3 ut365" anemometer

Fig. 4 Met One 531 portable particle counter

To measure the wind speed, an “ut365” anemometer was used. This lightweight system is equipped with the latest magnetic sensing technology able to display directly the wind flow speed on an LCD screen, as shown in Fig. 3.

A Met One 531 portable particle counter, as shown in Fig. 4, was applied to gauge the concentration of the particles. The instrument is capable of measuring volume, concentration, and the number of particles, together with showing temperature and humidity. This appliance could determine the particle concentrations for particle diameters consisting of: pm10, pm7, pm2.5, pm1. Also, it is also capable enough to measure the outgoing particles of diameters less than 10 μm .

In every station, the control key of fan speed was set at 5.5, 2.5, 1, and 7 m/s, each for 2 min, and then the particle counter was put on. After every 2 min, the concentrations of pm₁₀ particles were measured. Any changes in wind speed would change the particle concentrations. The emission potential of the particles at different wind speeds and at different points of the dried lake Bakhtegan was evaluated after inserting the obtained values in a table and zoning by ArcGIS and by spline method.

Results and discussion

The results obtained from the measurements in 35 stations are summarized in Table 1. This table gives the concentration of pm10 particles at different speeds in every 2 min work of the system, and also the increased speed is shown there. As it is seen, the particle concentration in most stations has been very low at speed 1 m/s, and as the speed increases, the concentration increases as well. Table 1 also represents eye-catching discrepancies among different stations.

For the sake of facility, the results of pm10 measurements are classified in three groups. The first group is dedicated to those situations where dust emission has been less than 250 mg/m³ at speeds 2.5, 1, 4, and 7 m/s. This group comprises the low-risk areas in our study the surface coatings of which are not degenerated by the created wind flow and where the surface airborne dust has not been remarkable. Figure 5 depicts the particle concentrations of the low-risk (low-potential) group at different speeds.

As shown in Fig. 5, most graphs are decreasing, which is a token that a hardened crust is formed over which there remain little dust particles which are then swept away by the wind blow. Only at station 12, it is noticeably discerned that the concentration of particles increases as the wind speed rises from 5 to 7 m/s, even though the concentration is about 120 mg/m³ (probably because the surface particle adhesion hinders emission).

The second group consists of the points at which the maximum of concentration at different speeds is beyond 250 mg/m³, but finally at speed 7 all the curves descend. These are the areas where albeit surface layer coating is not degenerated, removable storage of dusts on the surface is remarkable and capable of emitting sectional dusts in storms. However, the dusts would subside after a short time. Figure 6 shows the variations of dust emitted in these stations at various speeds.

As Fig. 6 confirms, the maximum of dust emission potential for this group in terms of concentration runs between 250 and 1650 mg/m³, but with the increment of speed, one observes significant decline in the particles amount. Some places, as point 9, has conspicuous removable particles at the minimum wind speed; however, the rises of most curves happen at speeds 2.5 and 4 which is the sign of terminal speed for transfer of particles in these points.

The places where maximum emission is above 250 mg/m³ and increase in dust goes along with increase in speed belong to the third group. These points have a great deal of dust storage, and probably there is no resistance in the surface layer whence a risky potential occurs at these points. The variation behavior of concentration due to increase

Table 1 Results obtained from the measurements of dust concentration in various wind speeds

N	X	Y	V: 1 m/s	V: 2.5 m/s	V: 4 m/s	V: 5.5 m/s	V: 7 m/s
1	217,285	3,259,927	36	41	56	41	44
2	218,986	3,258,057	48	177	255	330	176
3	219,436	3,256,269	20	53	1374	670	708
4	219,340	3,254,258	43	198	313	218	290
5	219,309	3,252,606	52	78	228	282	226
6	220,688	3,249,618	45	65	152	445	310
7	220,459	3,250,303	29	45	178	227	117
8	224,302	3,239,639	61	102	263	96	72
9	223,590	3,237,844	208	404	435	286	90
10	221,278	3,234,429	22	186	649	679	1126
11	223,078	3,244,722	24	49	93	197	112
12	223,823	3,242,561	27	36	112	80	120
13	222,481	3,240,210	21	18	38	36	42
14	220,445	3,238,156	20	30	120	133	104
15	218,515	3,237,435	21	38	112	178	111
16	216,952	3,237,960	23	26	408	959	2182
17	215,737	3,238,366	25	203	376	210	199
18	214,824	3,238,619	34	53	136	165	1415
19	213,859	3,238,952	32	82	434	863	785
20	212,857	3,239,257	46	39	128	212	326
21	212,211	3,239,315	33	50	142	1019	555
22	211,370	3,239,448	23	24	1155	1630	340
23	788,883	3,240,967	445	360	1522	1373	1639
24	787,029	3,243,267	34	254	601	3712	5257
25	785,098	3,244,758	4	23	76	59	24
26	782,229	3,244,885	10	78	182	202	62
27	780,814	3,244,682	58	238	2360	8261	9999
28	773,270	3,246,628	9	25	33	24	15
29	770,992	3,248,315	26	46	68	70	67
30	768,836	3,249,385	23	56	385	1347	1705
31	766,191	3,251,738	33	63	64	53	62
32	765,341	3,253,239	4	46	121	548	540
33	217,285	3,259,927	36	41	56	41	44
34	218,986	3,258,057	48	177	255	330	176
35	219,436	3,256,269	20	53	1374	670	708

Fig. 5 Particle concentrations of the low-risk (low-potential) group at different speeds **Fig. 6** Medium potential in dust emission

Fig. 7 High potential in dust emission

in speed on behalf of this group is shown in Fig. 7. The graphs have no peak point at the tested speeds, and even the capabilities of some up to emission of 10,000 mg/l by the wind speed are observed. These are the so-called high-potential points in Bakhtegan playa.

Figure 8 shows the results of zoning of particles at the various speeds of 1 m/s to 7 m/s. The largest area corresponds to 4 m/s because at this speed dust particles are observed on the hardened crust of the playa. As the speed grows up to 7 m/s, the particles in some parts were swept over time, and this more occurs as to those parts the surface shell of which are damaged by the wind and which might be steadily a source of dust. Therefore, the areas spotted in Fig. 8d have the potential of surface degeneration and dust emission when the wind is blowing. However, due to simplicity of the instrument and lack of hydraulic

communication, one could not assert precisely at which speed the shell generation occurs.

Figure 9 illustrates the percentage of the sensitive and high-potential points among the sampled ones. These are the points where the wind current was capable of degeneration in their surfaces, and their salt shells were either wiped out or very thin and vulnerable.

In this investigation, 29% of the points were of high potential, while the medium potential, with a share of 37%, belonged to those where their shells were not degenerated but covered with scores of dust particles. The remaining 34% designated the low-potential points where the tested wind speed was not capable enough of removing the shells.

Fig. 9 The percentage of high-, medium-, and low-potential points among the sampled ones

Fig. 8 Results of zoning of particles at the various speeds of 1 m/s (a), 2.5 m/s (b), 4 m/s (c), 5.5 m/s (e) and 7 m/s (d)

Bakhtegan wetland is protected by shells containing salt crystals due to high salinity in the wetland. This resistant crust caused by wind erosion in a situation where the crust is not damaged. These results confirm the studies conducted in salt wetlands in other parts of the world. (Sweeney et al. 2011; Webb and Strong 2011). Most areas have a high potential for dust production associated with coastal dry areas that have been damaged along local roads and rural roads. Most of the sites with a high potential for dust accumulation are also found on the beaches of the wetland, which confirms the role of moisture in reducing the potential for dust generation (Harland et al. 2017).

Conclusion

The simple little wind tunnel devised for our project, though along with drawbacks such as failure to model the real wind and storms flow, could demonstrate the behavior of different parts of the playa surface against wind flow and reveal the surface of vulnerable places.

The pictures obtained from the zonings could be also used as a guide in the management of dried playas. As observed, most of the vulnerabilities occurred in littoral places which had been the pathways of transport means of local people over years, leading to the shells degeneration. Hence, the results of the present research could be used by the executives in protection of the dried playas. Furthermore, simplicity and quick sampling as traits of our project facilitate the studies performed on playas, to the end of managing and protection of them and control of desertification.

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