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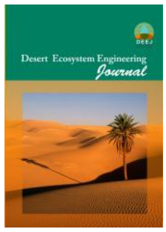

Analysis of Erosive Winds and Sand Drift Potential in Central Iran

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Abstract

In desert biome, the wind has an important role in erosion. The rate of wind energy and its direction variability have a significant control over the morphology and maintenance of aeolian landforms. The objective of this research is to investigate erosive winds and sandy sediments drift in Central Iran. For this purpose, the anemometric data from 1996 to 2015 of 11 stations were analyzed by WRPLOT software. To determine the wind direction, the annual wind rose and sand rose were drawn. The results obtained from the analysis of wind rose data revealed that the maximum frequency percentage was for the class 4-7 knot. The results showed that the dominant drift directions are NW, W, and SW toward N, NE, and E. The maximum and minimum total sand drift potential were 1245.2 and 57.9 vector units that are related to Abarkouh and Behabad stations, respectively.

Keywords: Wind erosion, Sand dunes, Wind rose, Sand rose, Yazd province.

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1. Introduction

Wind is one of the main factors generating erosion and causing degradation on the earth surface. The amount of wind energy and variability plays a significant role in the formation of aeolian faces, development, and movement of aeolian sediments, particularly sand dunes (Pearce & Walker, 2005). About 24 million ha of Iran's lands are influenced by wind erosion, 13 million ha of which being under the influence of sand dunes. Of this amount, over 5 million ha are active and semi-active sand dunes (Taksabz Consulting Engineers, 2002) Moving sand dunes are among the main dangers of wind erosion that can pose serious damages to transport networks, agricultural products, water resources, and residential areas (Refahi, 2009). Therefore, to prevent damage caused by moving sand dunes, studying the features of the agent of sand dunes movement and wind seems to be necessary.

Achieving easy and applied methods for the analysis of wind data has been among the main concerns of experts from the past up to now. In this regard, through the analysis of the anemometric data of a station, it is possible to predict the type of the formable sand dunes, the amount and direction of the Sediments movement. One of the methods proposed in this regard, which was used for the first time by Fryberger and Dean (1971), is the statistical analysis of the winds with speeds over the wind threshold velocity (Frybergerand Dean, 1979). In this method, various wind speeds in various directions with speeds over wind threshold velocity are converted into equal vector units and then sand rose is formed by plotting them at respective directions. This method has the capability of obtaining the wind potential in drifting the sand sediments and resultant drift direction (RDD), in addition to the analysis of the wind frequency and determining the direction of erosive winds. Also, the type of the faces formed in the region can be predicted and necessary management can be done by determining the occurrence of uni-direction, bi-direction, and multi-direction prevailing winds. Various studies have been done in this area. Some of these works are presented in the following:

Rajabi et al. (2006) – in a morphodynamic analysis of wind using spatial sand rose model in Sistan-Baluchestan province – obtained sand drift potential of 1376 and 1117 vector unit by the wind for Zabol and Zahak regions, respectively. They showed that RDD was toward the southeast, which exactly matches with the direction of 120-day Sistan winds. Ekhtesasi et al. (2006) analyzed wind erosion and determined the direction of the movement of sands in Yazd plain, based on a threshold velocity of 12 knots, as 82.5 V.U with 77° with respect to the geographical north. Ahmadi and Mesbahzadeh (2011) calculated sand drift potential of 401.09 and 490.51 V.U with the direction toward southwest through Fryberger velocity class method for Jask and Kerman, respectively. Philip et al. (2004) in a dynamic analysis of the movement of sand dunes in Egypt's Sinai desert estimated sand drift potential more than 400 V.U with the direction of movement from the west and northwest toward the east and southeast. Zuet al. (2008) in investigating the features of wind regimes in China's Taklamakan desert obtained a 200 V.U sand drift potential in low wind energy class according to Fryberger classification.

There is a relationship between wind speed and aeolian sediment transport rate, suggesting that it is a correct index for monitoring the wind erosion systems in long-term and can be used for the same purpose (Mainguetand Chemin, 1986). This study was aimed to analyze the erosive winds and determine the amount of discharge and RDD in central Iran to expand our knowledge of aeolian geomorphology.

2. Materials and Methods

2.1. Study area

Yazd province with an area of 73240 km^2 is located in the center of Iran. This area extends between 29° 35' to 35° 07' N latitude and 52° 50' to 58° 16' E longitude (Figure 1). Rainfall in this area is very rare and occurs mainly in winter. The average annual precipitation is 60 mm while the annual potential evaporation is 3480 mm. The climate is hyper-arid cold, with frosty winters and hot summers. The average annual temperature is 19℃ and the maximum and minimum temperatures are 43 and -7.2℃, respectively. Vegetation cover is sparse and sand dunes are the dominant geomorphologic phenomenon.

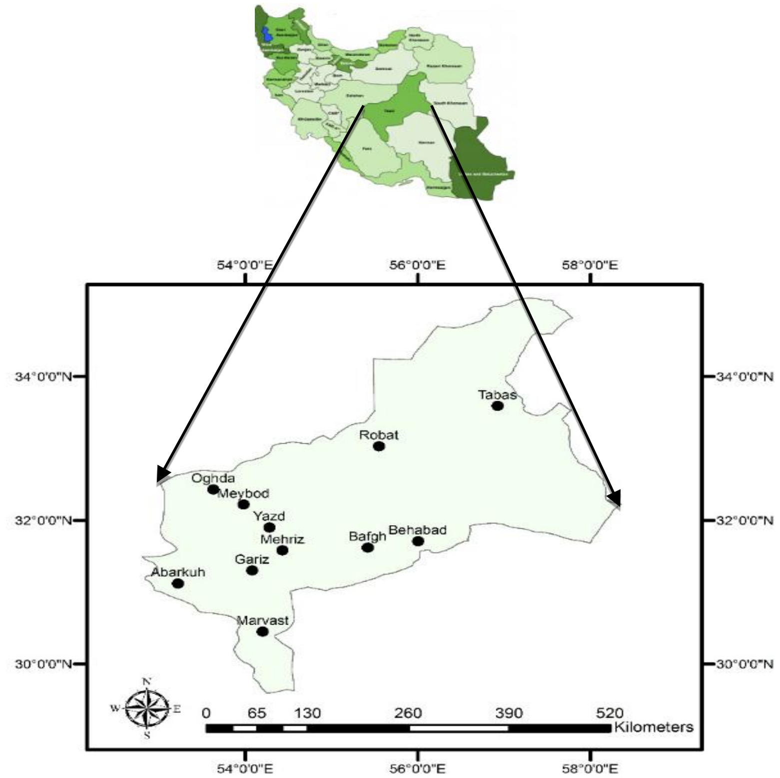

Figure 1: The geographic location of the study area

Anemometry data during recent 20 years (1996-2015) from 11 synoptic stations located in Yazd province were used as the most suitable and available statistical data. Meanwhile, necessary measures were accomplished to verify and reconstruct the current data (Table 1).

Table 1: The relationship between roughness length and wind erosion level

Station	Longitude	Latitude	Elevation (m)
Abarkuh	53° 13'	31° 07'	1536
Bafgh	55° 25'	31° 37'	989
Behabad	56° 02'	31° 50'	1432
Gariz	54° 05'	31° 18'	2007
Marvast	54° 12'	30° 27'	1546
Mehriz	54° 26'	31° 35'	1487
Meybod	53° 59'	32° 13'	1116
Aqda	53° 38'	32° 26'	1139
Robat	55° 33'	33° 02'	1188
Tabas	56° 55'	33° 36'	711
Yazd	54° 17'	31° 54'	1236

2.2. Methodology

2.2.1. Wind data analysis

To analyze anemometry data, WRPLOT 3.5 software, designed for wind statistical calculations and wind rose plot, was used. A wind rose is the simplest method for the statistical presentation of anemometry data and showing the frequency of wind direction and its speed in each direction. Since the software uses special formats to calculate and plot wind rose, to collect anemometry data legible wdConvert software was used.

2.2.2. Sand rose analysis and plot

Sand rose is a vector graph of sand drift energy representing wind erosion power and a relative amount of sand drift at various directions. Contrary to the wind rose in which the unit of arms size is in terms of wind speed, arms unit in sand rose is defined based on a vector unit (V.U). Considering various hypotheses, Leto-Leto (1978) proposed the following equation for estimating sand rose:

$$q = (C''\, p/g)V^2(V - V_t) \quad (1)$$

where q is the rate of sand drift (kg/m^3.hr), g is gravitational acceleration (m/s2), C" is a dimensionless constant determined based on the grain diameter, p is the density of air (kg/m3), V is the shear velocity of the wind (knot), and V_t is the shear threshold velocity of the wind (knot). Fryberger (1979) simplified the relation as follows:

$$Q = V^2(V - V_t)\, t \quad (2)$$

where Q is the amount of sand drift, which is shown in the form of vector unit, V is wind velocity in the height altitude of 10 m (knot), V_t is wind threshold velocity (knot), and t is the frequency of winds with a velocity more than threshold velocity (%). Indeed, V^2 (V – V_t) is weight factor indicating that stronger winds have more weight and weaker winds have less weight. To reduce weight factor and simplify sand rose plot, the weight factor is divided by 100 (Al-Awadhi et al., 2005). The first stage in calculating sand drift potential is determining erosion threshold velocity. In this study, given the investigation done so far, erosion threshold velocity was between 10.9 to 13.6 knots. After determining the amounts of weight factor and considering the amounts of the frequency of each velocity class, the drift potential (DP) values were calculated for each geographical direction their sum in each velocity class was considered as DPt.

Fryberger and Dean (1979) extracted various indices from the sand rose plot that can be useful for determining the direction of sand movement as follows:

Total drift potential (DPt): It is a numerical or scalar value obtained from the sum of DP values in various directions. In fact, DPt is an index showing the total wind energy to drift sand in the region. Fryberger and Dean (1979) classified wind erosion power based on the wind drift potential index in Table 2.

Table 2: Fryberger and Dean’s (1979) classification of wind energy using DP

DP (V.U)	Wind Energy
< 200	Low
200-400	Intermediate
> 400	High

- Resultant drift potential (RDP): It indicates the resultant sand drift power vector obtained from a vector sum of DP values at various directions of 8 or 16.
- Resultant sand drift direction (RDD): It denotes the direction of sand movement resultant vector during a given year, month, or season.
- Uni-directional index (UDI): UDI or variability of sand drift is the resultant ratio of drift potential to the total drift potential. Fryberger and Dean (1979) classified wind direction variability based on UDI (Table 3).

Table 3: Fryberger and Dean’s (1979) classification of wind energy using UDI

UDI	Wind Energy	Wind Direction Category
<0.3	Low	Complex/Obtuse bimodal
0.3-0.8	Intermediate	Obtuse/ Acute bimodal
> 0.8	High	Wide/Narrow unimodal

Given the complexity and high volume of statistical calculations compared to sand rose plot, sand rose graph was used to calculate and plot. The software, which was originally designed based on Fryberger and Leto’s proposed equations and relations (Ekhtesasi et al., 2006), can analyze the respective sand roses statistically and plot them receiving respective station’s anemometry data and wind erosion threshold velocity of various adjacent facies. Plotted sand roses are able to present sand drift potential by the wind and its direction.

The summary of the steps taken in this study is presented in Figure 2.

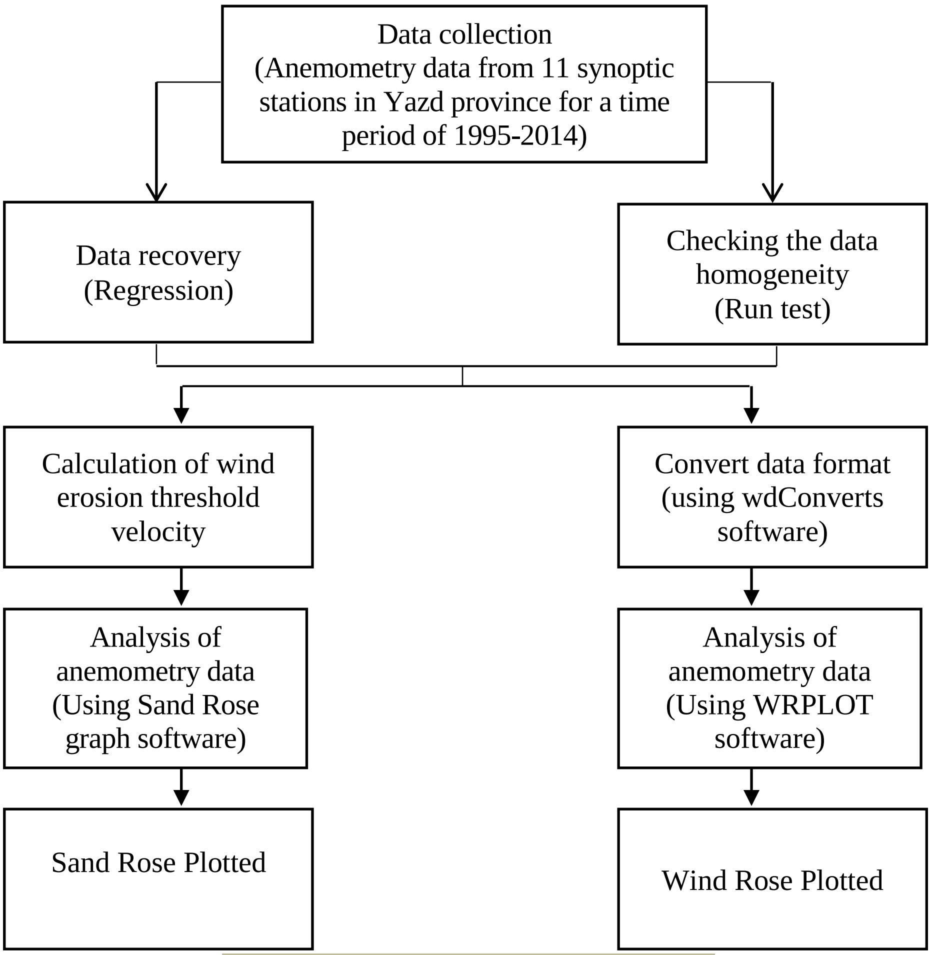

Figure 2: The summary of the investigation

3. Results and Discussion

The analysis of the anemometry data studies in this work shows that about 12.6 to 65.5% of 3-hour registered data are in a calm condition and in the other times the velocity more than 1 knot prevails the region. The minimum and maximum percentages of calm winds belonged to Marvast and Tabas stations, respectively. Also, the results showed that in most of the studied stations, less than 1% of the registered data were of a velocity more than 22 knots, 1% of them have a velocity more than 34 knots are observed in Abarkuh, and less than 0.2% of them with a velocity more than 34 knows are observed in Gariz, Marvast, Mehriz, and Meybod stations. Except for Abarkuh station, in all other stations, the maximum wind frequency was in 4-7 speed class and then in 7-11 class. Analysis of average wind speed in the studied region showed that the maximum and minimum average wind speeds were 7.68 and 2.43 knot, which were for Marvast and Yazd stations, respectively.

Table 4: The frequency percentage of wind speed class in Yazd province stations

	Abarkuh	Bafgh	Behabad	Gariz	Marvast	Mehriz	Meybod	Aqda	Robat	Tabas	Yazd
Calm	32.5	49.6	53.1	19.3	12.6	14.6	17.5	28	25.1	65.5	18
1-4	0.1	3.1	17.2	5.1	0.2	3.7	0.4	0.3	0.5	0.3	0.2
4-7	24.5	21.3	17.6	36.1	36.6	39.9	36.3	30.2	39.9	20.1	50
7-11	24.9	15.8	9.4	26.6	31	28	27.2	24.2	25	8.2	23.4
11-17	9.6	7.8	2.2	9.5	14	12.4	13.8	13.1	8.3	5.4	6.5
17-22	4.5	1.9	0.4	1.4	4.3	1	3.6	3.2	1	0.4	0.8
22-28	1.3	0.4	0.1	0.6	0.8	0.2	0.4	0.7	0.2	0	0.1
28-34	1.6	0.2	0	0.3	0.4	0.1	0.5	0.3	0	0	0
> 34	1	0	0	0.1	0.1	0.1	0.2	0	0	0	0
	6.82	4.34	2.53	6.2	7.68	6.68	7.27	6.39	5.7	2.48	2.43

Table 5: The frequency percentage of 8 geographical directions in Yazd province stations

Stations	N	NE	E	SE	S	SW	W	NW
Abarkuh	9	6.9	8.7	5.7	4.4	7.5	14	10
Bafgh	7.8	4	2.9	12	5.1	2.9	3.6	11.7
Behabad	11	2.7	2.5	4.6	9.9	2.3	4.1	9.4
Gariz	4	2.6	6.5	12	4	4.2	21.3	24.8
Marvast	14.2	8.3	5	14.6	15.7	10.1	7.8	11.4
Mehriz	11.5	18.5	12.8	7.6	6.2	6.9	15.8	15.6
Meybod	29.3	12.8	5.2	7.8	6.8	5.5	2.3	12
Aqda	9.3	15	10.8	2.5	5.7	6.5	16.1	5.6
Robat	29.9	2.4	1.5	11.5	9.7	3.4	4.3	15
Tabas	6.9	7.3	3.3	1.4	1	1	3.9	9
Yazd	5.8	3	7.5	16.4	6	8	18.7	15.6

As shown by the plotted wind roses (Figure 3) and Table 5, the frequency percentage of wind direction is different in various stations. But, in general, in the studied stations, the maximum frequency of wind was in the north, northwest, and west directions. Abarkuh, Meybod, and Robat had unidirectional prevailing winds but in Gariz, Bafgh, and Aqda stations, bidirectional prevailing winds were observed. In other stations, prevailing winds were of a multidirectional type. Also, prevailing winds in none of the studied stations were in the east or southwest directions.

Results of the calculations and preparation of sand roses for the studied stations are shown in Figure 4. Calculation of DPt showed that the minimum and the maximum DPt belonged to Behabad (57.9 V.U) and Abarkuh (1245.2 V.U) stations, respectively. According to Fryberger and Dean’s classification (Table 2), wind erosion potential was low in Behabad, Mehriz, Robat, Tabas, and Yazd, average in Bafgh, Gariz, Marvast, Meybod, and Aqda, and high in Abarkuh. Resultant drift direction (RDD) in the studied region showed that sand sediments were moving toward the north direction in Robat, toward the northeast in Abarkuh, Behabad, Marvast, Mehriz, and Aqda, toward the east in Bafgh, Gariz, Meybod, and Yazd, and toward southeast in Tabas.

Analysis of unidirectional index in the region showed that, according to Fryberger and Dean’s classification (Table 3), Bafgh and Behabad with a high unidirectional index were of complex multi-directional winds with an acute angle. Other stations were of bi-directional winds with an obtuse angle and average uni-directional index. It is worth mentioning that in sand rose analysis, winds of speeds lower than erosion threshold velocity were omitted by the software. Results in Table 6 showed that the maximum discharge was 59.86 kg/m.s and belonged to Abarkuh station, of this amount 46.15 kg/m.s was aligned with RQs in the northeast direction (60°). The minimum discharge was 1.94 kg/m.s and belonged to Behabad station, of this amount 0.45 kg/m.s was aligned with RQs from the southwest toward the northwest. Total sand flow (TSF) and minimum sand flow were 174,805 and 5,656 ton/m per year and belonged to Abarkuh and Behabad stations, respectively. Of this amount, 134,855 and 13,227 ton/m in per year were aligned with the DSF.

Table 6: Amounts of sediment discharge and transported sediments

Stations	Qs (kg/m.s)	RQs (kg/m.s)	TSF (ton/m.year)	DSF (ton/m.year)
Abarkuh	59.86	46.15	174805	134855
Bafgh	8.47	1.64	24729	4794
Behabad	1.94	0.45	5656	1327
Gariz	15.8	10.59	46133	30914
Marvast	21.01	9.57	61354	27954
Mehriz	8.39	3.06	24512	8945
Meybod	23	8.75	67165	25554
Aqda	15.6	8.88	45557	25931
Robat	4.33	1.51	12642	4407
Tabas	2.51	1.5	7331	4388
Yazd	4.57	2.56	13348	7477

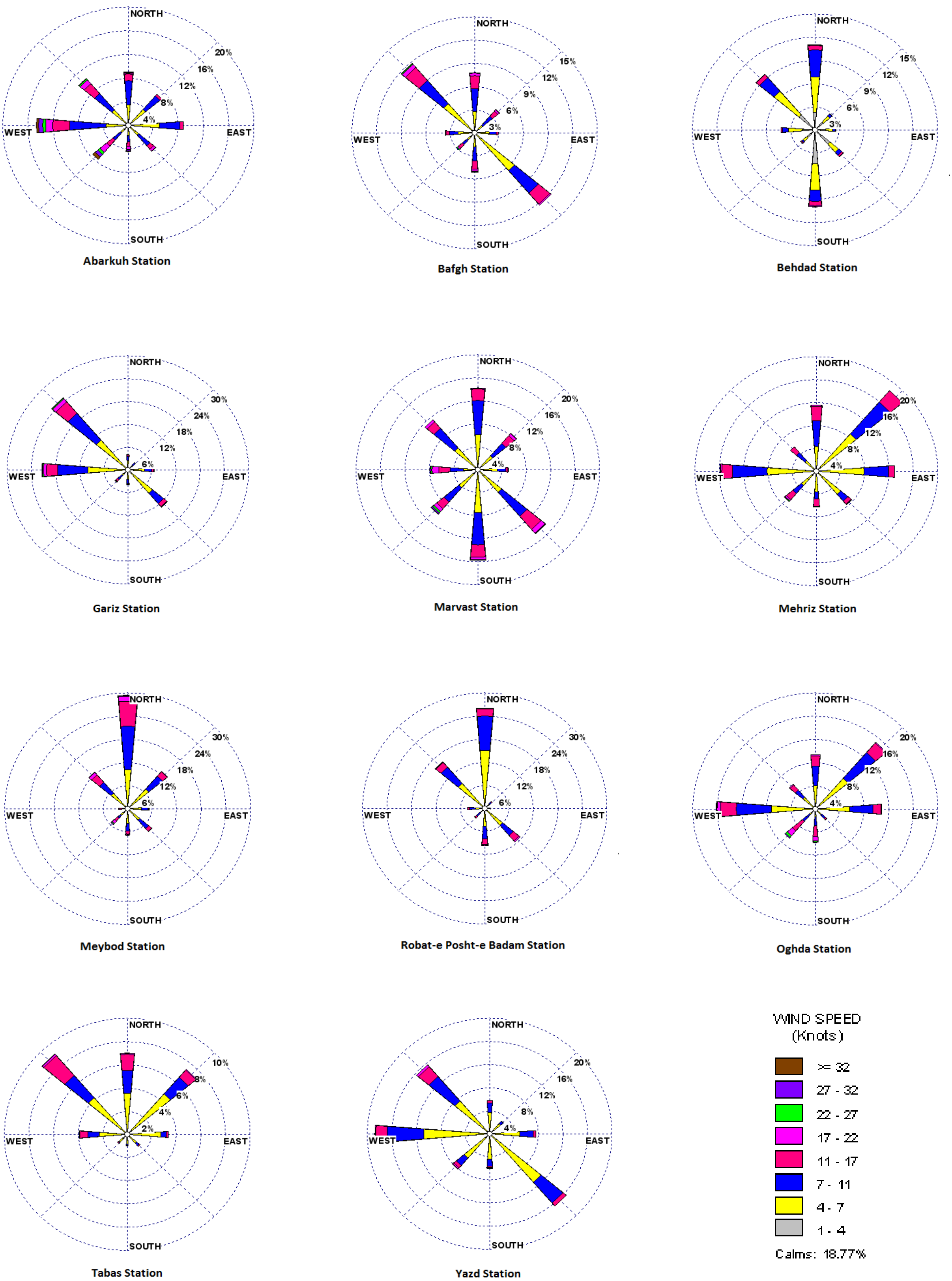

Figure 3: Annual wind rose in the studied stations (1996-2015)

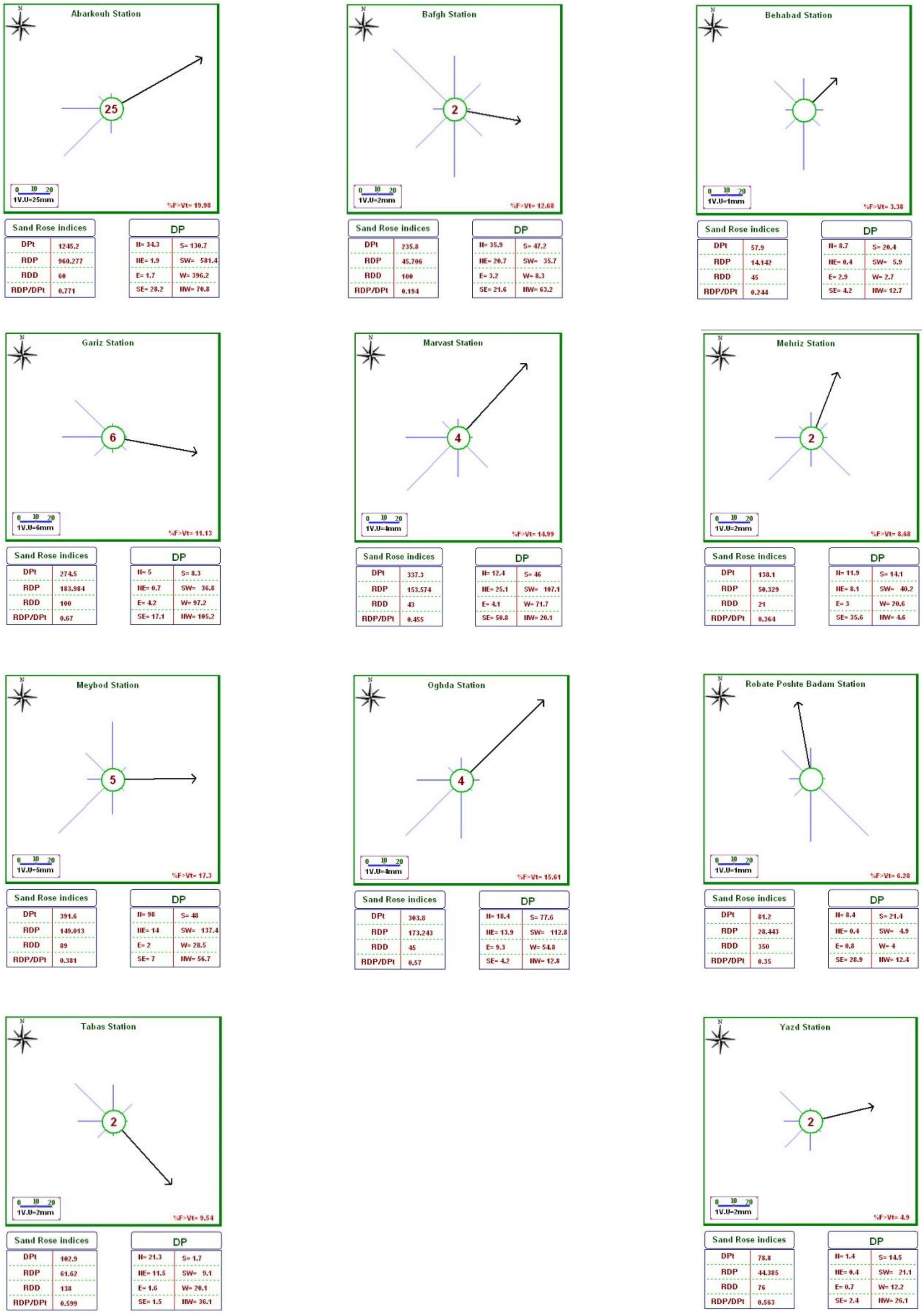

Figure 4: Annual sand rose in the studied stations (1996-2015)

Annual wind roses in the studied region show that dominance of prevailing winds over various desert areas of Yazd province is different and this prevalence is due to windy and morphologic conditions of the region. However, prevailing directions of north, northwest, and west were of the highest frequency. Although wind directions with the highest frequency and speed can be shown based on the wind rose, the most influential erosive winds and sand drift cannot necessarily be attributed to the direction. Thus, to analyze anemometry data, the wind rose plot is not sufficient; rather, incorporating soil erosion threshold velocity by the wind and using sand rose graphs are also needed. Because in this case winds with a speed less than erosion velocity are omitted, it is possible that wind rose and sand rose are not in the same direction. In the present study, in most of the stations, the wind rose and sand rose was in the same direction. But, in stations such as Behabad, Meybod, and Robat, the resultant direction of sand rose was opposite to the wind rose direction. Ekhtesasi et al. (2006) also found similar results in their analysis of wind erosion of Yazd plain. This point must be considered in designing constructs and particularly windbreaks, and direction of prevailing winds should not be the sole yardstick in their design.

The highest amount of sediment drift in the region occurred by the winds with the average velocity and high frequency. This result is contrary to the idea mentioned about the moment and stormy winds because the winds with a velocity less than erosion threshold velocity were omitted and those with high velocity, due to their low frequency, had no remarkable role in the formation of sand dunes. Zareiyan (2007), in his analysis of sand dunes of south Iran, emphasizes the influential role of the winds with average speed and high frequency on drifting the sediments.

Maximum and minimum amount of total sand flow belonged to Abarkuh and Behabad, respectively. Through the analysis of sand drift potential, this phenomenon is justifiable in the sense that transported sediments volume is increased with an increase in the velocity of the winds with a speed more than erosion threshold and consequently sand drift potential. In a similar study in China's Taklamakan desert, Mainguet and Chemin (1986) stated that there is a significant relationship between the speed frequency of winds of more than erosion threshold velocity and aeolian sediment transport rate.

Given the uni-directional index, the type of influential wind regime in the formation of sand dunes and sediment morphology can be predicted. In other words, knowing wind uni-directional index, type of uni-directional and bi-directional winds in the same or opposite direction or multi-directional winds, it is evident that this issue is considered as one of the influential factors in the formation of aeolian facies such as Barchan, Seyf, and Barchanoid. Researchers such as Moursey et al. (2002), Wang (2002), and Saqqaand Atallah (2004) present similar results. Also, prevailing direction of sand sediment movement in these regions was from northwest, west, and southwest toward the northeast, east, and southeast.

4. Conclusions

The study of erosive winds and sand drift potential is still in its beginning stage. Yazd Province (Iran) is one of the important area exposed to wind erosion. The Fryberger method is a useful approach for evaluating sand drift potential by the wind. The results of this work revealed that the dominant drift direction is from NW, W, and SW toward N, NE, and E. The maximum and minimum TSD potentials were 1,245.2 and 57.9 V.U, which are for Abarkouh and Behabad stations, respectively.

In the end, we can state that using the results of this study help us to recognize the velocity and direction of erosive winds, sediment drift potential, the amount of discharge, the direction of sediment movement, and also the type of land morphology. Knowing this issue would be useful in land management and recognition of wind erosion strategies.

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