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The sand dunes migration patterns in Mesr Erg region using satellite imagery analysis and wind data

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Abstract
Understanding the situation, behavior and the nature of sand dunes and also their location, transport and deposition are very important. On the other hand, the importance of sand dunes is due to the impacts that they have on water and soil resources, flora and fauna and human infrastructure. This study, looks at the development patterns of sand dunes in Mesr erg region. In the first part, data and satellite imagery were analyzed with different time intervals. In the second part, wind data of Ardestān, Isfahan, Kashan, Natanz, Khoor and Byabanak stations were studied to monitor the status of the wind regime, and its impact on the dynamics of the Mesr sand dunes. The results indicate that the area affected by the prevailing winds from Northwest Southeast direction during the cold days during the entire year, so that major translocations fit this trend in the erg surface. However, average Migration over the dunes was measured 8 meters per year. During the summer, following the establishment of a low-pressure system over the Dasht-e Kavir, winds from the Northeast direction result in irregularities in the sand dunes morphology, therefore evidence of these irregularities, is the dunes Migration to the Southwest direction.

Keywords
Mesr Erg, sand dunes, Sand Migration, satellite imagery, wind data.

1. Introduction
Sand dune is one of the landforms in desert areas, which have been surrounding the vast majority of the Iranian deserts. Wind is an erosive factor, which has its own speed, direction and turbulence and determines the form and rate of sand dunes activity (Tsoar, 2005). On one hand, winds direction shifting on the sandy surface is resulted from pressure pattern of dominated on the related areas in different seasons. On the other hand, with regard to number of high peaks, desert plains extend and topographic conditions in plains, and local winds at different times, may occur in a basin. However, in such circumstances, the ergs are located along the dominated or the strongest winds (Mahmoudi, 2002). Aeolian Sand transports is a complex process, and influenced by many variables, including wind conditions (Lancaster, 1985; Anderson & Haff, 1988; Gillette et al., 2001; Zou et al., 2001; Liu et al., 2005), grain size and sand surface

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moisture, (Jackson, 1998; Wiggs et al., 2004), surface crusting (Leys & Eldridge, 1991), topography (Iversen & Rasmussen 1994; Hesp et al., 2005), and Vegetation cover (Buckley, 1987; Kuriyama et al., 2005).

The importance of sand dunes studies is due to the impacts that they have on water and soil resources, flora and fauna, human infrastructure, and roads. Sand drifting can lead to losing agricultural lands, burying residential buildings, railways, highways, and other infrastructures in many areas of the desert (Zhu et al., 1980; Lei et al., 2003; Dong, 2004). Bagnlod (1981) has done the first studies on the movement of sand dunes. In recent years, many researches have been done on the cognition of sand dunes processes, which include the study of the winds and sands migration in different dunes and needless to say that significant progresses have been obtained. In this regard, there is no doubt that remote sensing technique and its abilities, as well as the optimal time sequence of satellite imagery in mapping erg areas have a fundamental performances. Using these images, substantial area of sand dunes can be examined in a short period of time, and then we can talk about the identification of active dunes, expansion and relocation of them.

Hamdan et al. (2016) have examined morphological characterization and the movement of Barchans in the Southeast of the western desert of Mesr. In this study, dunes movement were examined using Google Earth and images in various time periods. As a result, Migration of 3 to 10/82 meters per year was calculated, which is a serious danger for infrastructures and lands under cultivation. Ihab and Verstraeten (2012) have examined sand fields based on analysis of multi-temporal Landsat TM images. Here, the near-infrared bands have been used for RGB images. Hermas et al. (2012) have examined sand dunes migrations using multi-temporal images pixels correlation in the Northwestern Mesr desert. The results show shifting of dunes to the East and Southeast directions. Sparavigna (2013) has studied the migration of sand dunes using Google Earth's images. Although the Migration of sand dunes is quite slow, it can be a challenge or even a threat to human activities. Besides, in sand dunes relocation, climate change could have catastrophic consequences on local communities. Ghadiry and Koch (2010) have developed and used monitoring systems to study sand dunes migration in western Mesr desert. However, sand dunes drifting is one of the most serious economic and psychological problems in Mesr. Furthermore, dunes Migration rate is variable and can ranges from 1 to 15 meters per year. Zhang et al. (2015) has studied relocation in Jaran desert using the wind regime in China. Baitis et al. (2014) have examined sand dunes patterns using LIDAR images. Yang et al. (2014) have studied wind regime and the movement of sand dunes between Badyan Jaran and Tengr deserts, in China's central plateau of Alexa. Moreover, the results show that the transportation of sand in the spring and winter is 99.8 % of the total annual value. Sherman and Li (2012) have predicted the sand dunes Migration rate. In this work, models of Bagnold, Kawamura, Zingg, Owen, Kadib, Hsu, Lettau and Lettau and Sorensen have been used to provide a comprehensive model to predict the rate of sand transportation.

The main objective of this research is to monitoring sand dunes changes and also calculating their Migration rate using multi-temporal satellite imagery in Mesr Erg region.

2. Study area

The study area, is located in the city of Khour & Biabanak in Esfahan province. It is located also in the South-East of Semnan city, and East of the Salt Lake. Furthermore, Mesr erg is situated near Mesr, Amir Abad, Farahzad and Mohammad Abad Koore Gaz villages in the Dasht-e Kavir region. The erg area is about 700 km^2. This area lacks permanent drainage network and most of formations of Mesr Erg region are sand dunes of the Quaternary period. Moreover, in terms of tectonics, the region is free of major faults, and mostly minor faults are obvious. Rashid Kuh and Kuh-e-Sorkh are two major mountains of this area. It worth mentioning that the highest elevation is located in the southern parts (2208 m), while the lowest is 700 m. Additionally, general slope trend of the region is from southern margins toward the dunes area (Fig. 1).

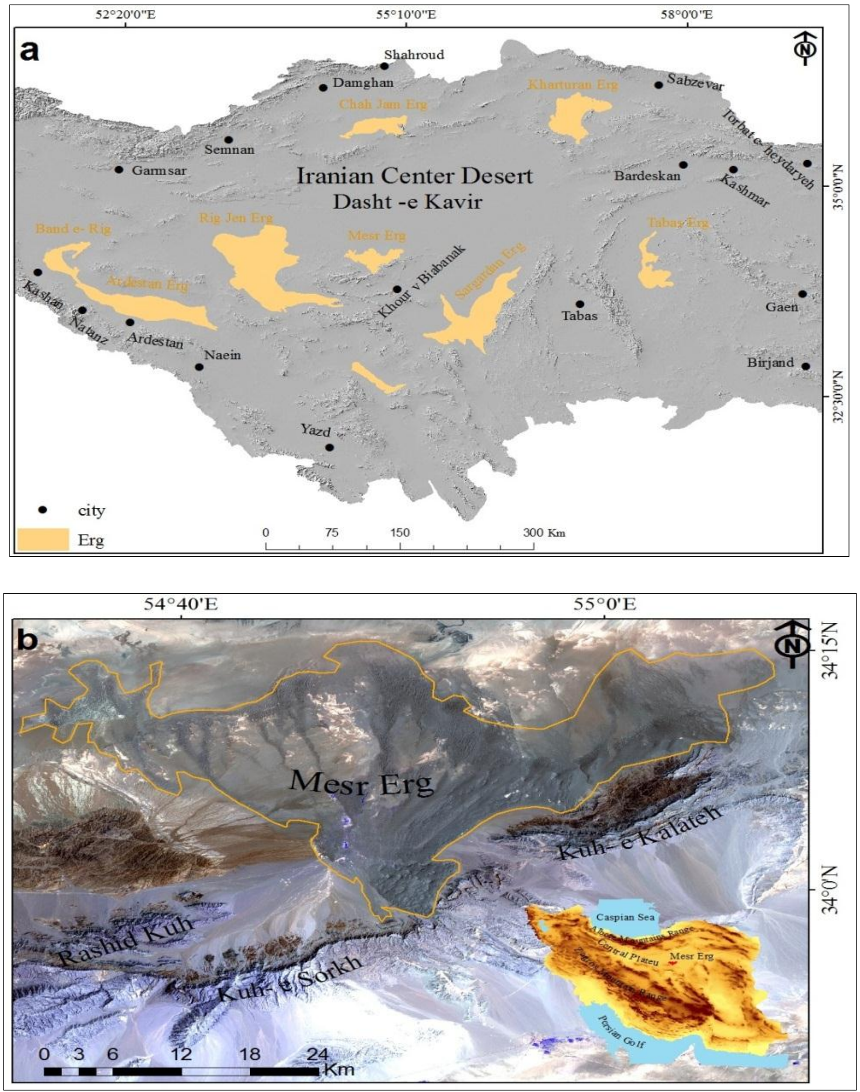

Fig 1. a)Location of Iranian Center Deser (Dasht –e Kavir Ergs), b)Mesr Erg

3. Materials and Methods

To study the changes and Migration of sand dunes, this study was conducted in two stages.

At the first stage, to evaluate changes in the range of sand dunes in the study area, Landsat images were used for years 2003 and 2016. Moreover, to detect the changes in the Mesr Erg range the ENVI software is used. The results of this section can be important in the overall assessment of the area.

Additionally, in order to detect the changes trend in those parts where significant shifting was occurred, we used either Landsat or the Google Earth images with different time intervals. It worth mentioning that for georeferencing the Google Earth images of recent years (2012-2016) the Stitch Map Software is used.

At the second stage, wind data of meteorological stations in the region, to understanding the wind regime and also knowledge of wind erosion potential were used (Table 1). Moreover, to draw the sand rose, the Sand Rose software was used. Sand rose, is the Graph of Portable sand by wind energy, which was used by Fryberger and Dean (1979) for the first time. In order to draw this Graph, winds that are faster than erosion velocity threshold are developed into vector units as sand drift potential, which sand rose in different directions is drawn by drawing them.

According to unit’s classification by Fryberger and Dean (1979), if sand drift potential be more than 400 DP, then the wind erosion power is high, and variability of wind directions is low. In contrast, if sand drift potential be less than 200 DP, the wind erosion power is low, while variability of wind directions is notable (Table 2).

Table 1. Meteorological data stations information

Station	Lat/Lon	Elevation	Period of record used
Ardestan	52.38/33.38	1252	1992-2010
Esfahan	51.66/32.61	1550	1961-2010
Kashan	51.45/33.68	982	1971-2010
Khour & Biabanak	55.08/33.78	845	1987-2010
Natanz	51.90/33.53	1684	1992-2010

Table 2. The classification of wind energy environments using drift potential (DP) and directional variability (modified from Fryberger & Dean, 1979)

DP(vector units)	Wind energy environment	RDP/DP	Directional variability	Directional category (probability distribution)
<200	Low	<0.3	High	Complex or obtuse bimodal
200-400	Intermediate	0.3-0.8	Intermediate	Obtuse or acute bimodal
>400	High	>0.8	Low	Acute unimodal

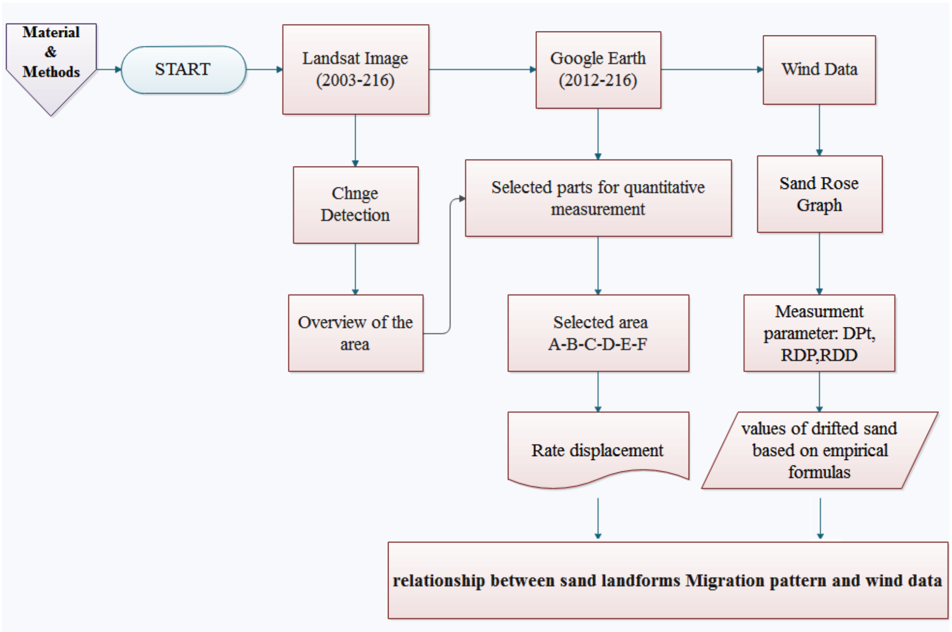

Fig. 2. Methodological flow chart in this study.

4. Results

4.1. Satellite image processing

Mobility is the most important characteristic of sand dunes. In this regard, special attention should be paid to the importance of wind in changing the sand dunes morphology. In addition, studies of sand dunes migration, provide basic knowledge about wind processes and sand transfer values.

In this study, monitoring and detection of the sand dunes relocation rate, have been considered based on the use of Landsat images (years 2002-2016). At the first stage, the regions that have been faced changes were identified using the change detection technique for the entire range of Erg (Fig. 3). Based on the output map, marked areas with the blue color have been experienced the maximum changes, and also, in this sections, sand dunes have been more developed. The differences between the two images within the sand dunes area, were estimated at about 29 km^2. However, the pattern of sand dunes Migration, represents relocation from the Northwest to the Southeast.

At the next stage of the study, to understand the changes rate and relocation trend, Google Earth images were used (years 2012 and 2016; Fig. 3). Furthermore, the region with significant changes has been selected for a closer look. Moreover, using Stitch Map software the georeferenced images have been extracted (Fig. 4).

It worth mentioning that, from the six selected zones on the Erg surface, a total of 251 cases of sand dunes were quantitatively analyzed. Based on the results, the direction of Migration on the Erg surface is mainly directed Northwest–Southeast. Besides, in zones B and C, the changes trend is North-South and West-East, respectively. An important point is that, care must be taken that on the study area surface in addition to the general Migration trend to the Southeast, a seasonal relocation of Northeast-Southwest is occurred and this indicates that winds from Northeast also have role in the movement of sand dunes in the region. According to Table 3, the greatest amount of Migration was found for zone D with the amount of 51.72 m, in contrast, the lowest value was calculated about 31.78 m for zone C. In addition, Migration average rate for period of 5 years has been calculated. Here, the maximum Migration belongs to zone D that is 10.34 meters per year. While, the minimum one allocated to zone E is 6.64 meters per year (Table 3, Fig. 5).

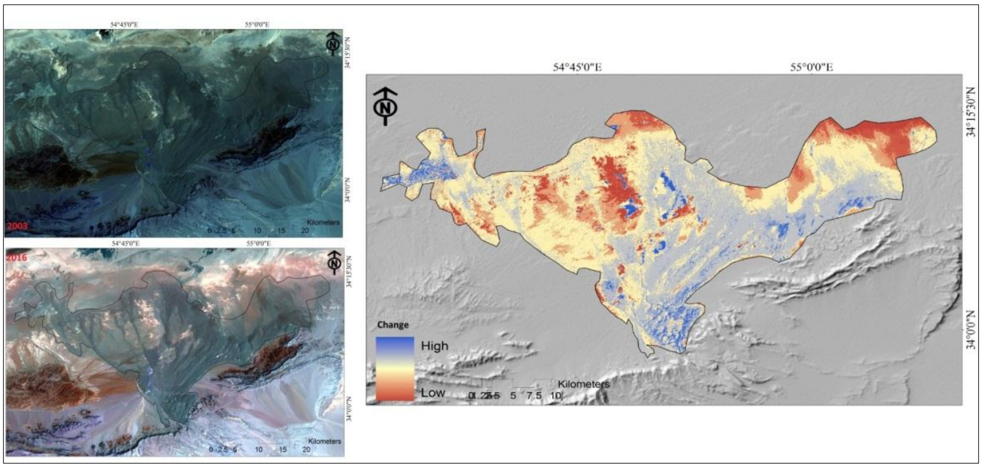

Fig 3. Changes in Mesr Erg region between the years 2002-2016.

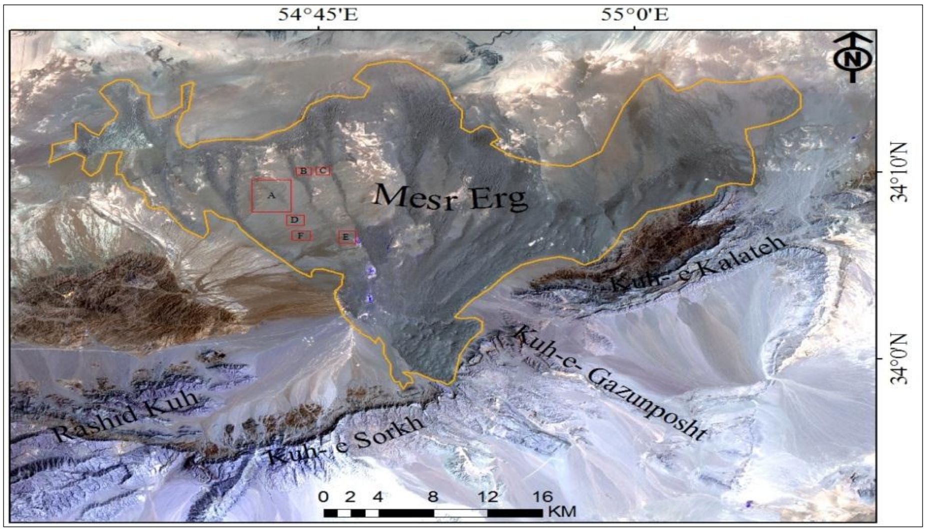

Fig. 4. Mesr Erg region and the location of studied dunes.

Table 3. The amounts of sand dunes migration in Mesr Erg region

Zone	Number of investigated sand dunes	Area (M^2) 2012	Area (M^2) 2016	Differences (M^2)	Migration direction	Migration amount (m)	Migration average (m/year)
A	142	664502	882068	217566	NW-SE	44.70	8.94
B	31	61918	54176	7742	N-S	39.22	7.84
C	25	26657	30063	3406	W-E	31.78	6.35
D	26	36464	33538	2926	NW-SE	51.72	10.34
E	17	54207	56539	2332	NW-SE	33.23	6.64
F	10	24086	21345	2741	NW-SE	46.88	9.37

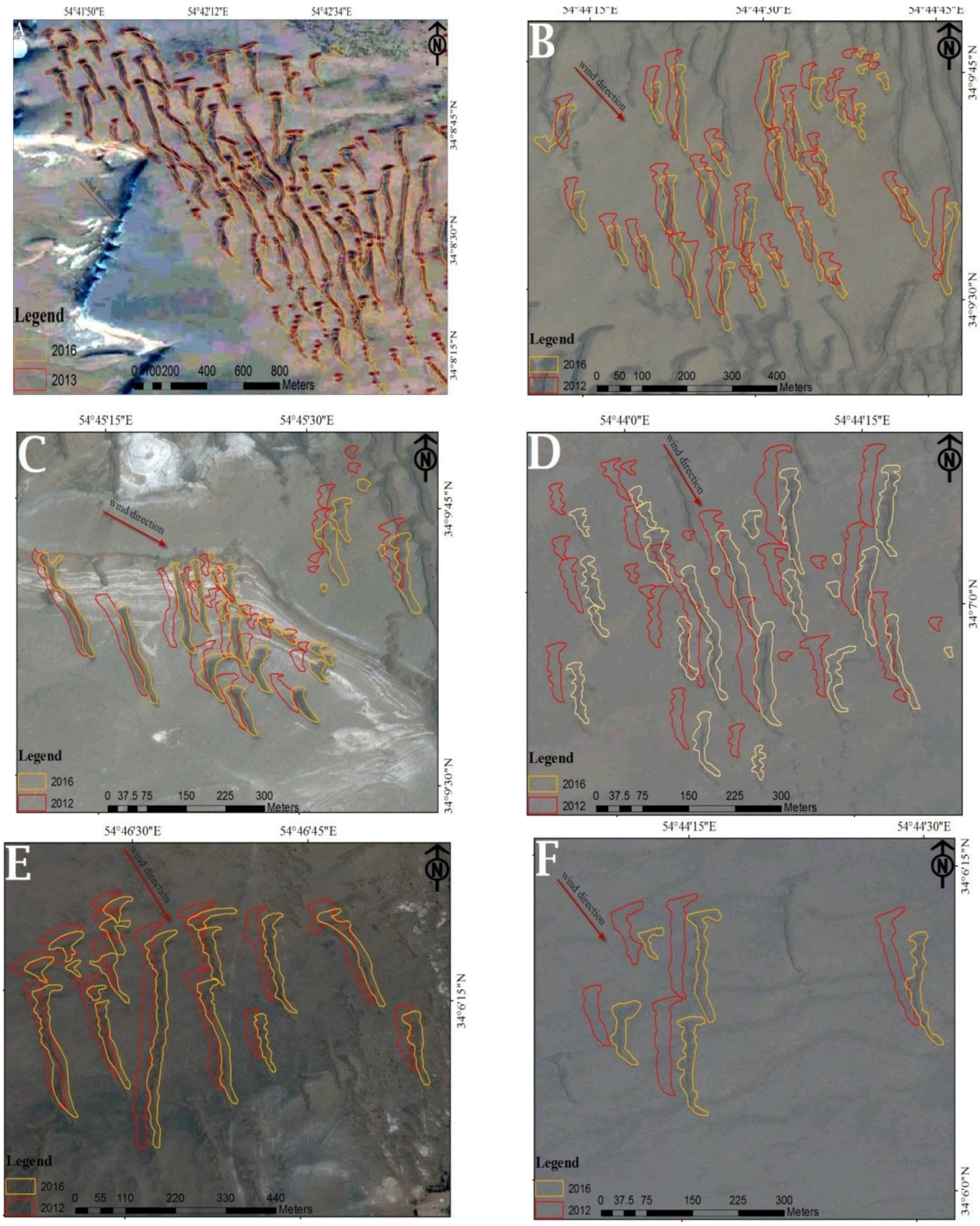

Fig. 5. Sand dunes Migration patterns during years 2012-2016.

4.2. Wind regime and sand drift

Sand drifting is the smallest part of the sand migration process (Gillies et al., 2006; Udo et al., 2008; Lancaster et al., 2010; Delgado-Fernandez & Davidson-Arnott, 2011; Gillies & Lancaster, 2013; Yurk et al., 2013). The study of sand drift, has been considered as the first step in understanding the processes of sand drifting.

The results of statistical parameters for the studied stations are given in Table 4. Based on these results, the maximum and minimum values of sand drift potential (DP) belong to Ardestān and Kashan stations, respectively. Refering to Table 2, wind energy in Kashan and Khour & Biabanak stations is weak. While, in Natanz and Esfahan stations is moderate. Moreover, Ardestān station with the maximum value of 528 (TDP) was placed in class with high wind energy. Furthermore, resultant drift potential (RDP), is the column that shows the sand drift potential (Table 4). Data in this column indicates that, the highest and lowest sand drift potential belong to Ardestān and Kashan stations.

The uni directional Index (UDI) is the ratio of final amount of sand drift than the total sand drift potential. According to this index and Fryberger and Dean’s classification (1979), directional variability (RDP/DP) for Ardestan station is high. Needless to say, unidirectional powerful winds, provide conditions to create transverse dunes, barchans and Seif. However, this index for Esfahan, Kashan, Natanz and Khour & Biabanak stations is located in the moderate group with obtuse angle bi-directional winds.

Resultant drift direction (RDD), is the column that shows the resultant direction of sand drift. Refering to the data of this column, it seems that all stations have a direct impact in the migration trend of sand dunes on the Erg surface. Using data from these stations and keeping in mind that they are far from the study area (Khour & Biabanak station is the closest station to the studied area), understanding the directions of the winds on the Erg surface that influence the sand dunes movement patterns ,are important. Since, the sand drift general trend is Northwest-Southeast and West–East, therefore, in this regard winds from the South and Southwest result in irregularities in sand drift patterns on the Erg surface.

Table 4. Statistical summary of annual parameters related to sand transport: drift potential (DP), resultant drift potential (RDP), directional variability (RDP/DP), and resultant drift direction (RDD)

Station	DPt	RDP	RDP/DP	RDD
Ardestan	528.4	1598.59	0.174	342
Esfahan	334.3	244.75	0.732	58
Kashan	122.7	62.29	0.508	71
Khour & Biabanak	142.5	102.42	0.719	100
Natanz	338.3	247.73	0.732	55

Table 5. The winds percentage with maximum velocity threshold of erosion in studied stations (values are expressed in percentage)

Station	Season	N	NE	E	SE	S	SW	W	NW
Ardestan	Spring	9.21	31.35	30.5	26.47	48.57	57.14	28.57	21.03
	Summer	7.22	41.56	43.76	22.82	46.61	15.67	12.1	12.52
	Autnmn	2.26	6.38	15.29	20.35	38.18	33.94	16.39	7.8
	Winter	2.37	9.45	13.48	24.39	40.28	55.7	15.86	14.27
Esfahan	Spring	3.8	2.63	6.5	9.98	16.69	29.4	14.78	7,57
	Summer	1.54	2.6	7.66	11.2	7.06	9.29	5.03	2.45
	Autnmn	1.32	0.63	0.81	2.83	10.03	20.94	7.72	3.09
	Winter	4.45	1.35	2.06	7.01	19.63	30.23	14.66	6.85
Kashan	Spring	4.79	4.23	5.21	5.54	10.86	19.44	17.19	8.45
	Summer	2.78	5.63	8.06	6.32	3.21	4.82	3.69	2
	Autnmn	1.9	1.69	0.78	2.46	2.46	12.67	8.5	4.07
	Winter	3.3	1.95	1.86	2.17	7.58	18.05	18.59	7.26
Khour & Biabanak	Spring	7.62	6.78	1.97	4.52	5	13.68	22.63	9.84
	Summer	5.27	6.18	2.82	2.59	3.87	5.17	3.49	2.67
	Autnmn	2.6	2.53	0	2.82	2.63	8.85	10.67	3.85
	Winter	3.04	1.47	0	5.71	4.68	13.33	18.96	8.44
Natanz	Spring	4.27	3.34	2.54	6.19	26.42	30.21	32.17	11.66
	Summer	2.63	3.67	4.36	2.58	5.18	6.79	7.01	5.35
	Autnmn	2	1.08	1.08	4.61	22.37	18.76	21.2	6.39
	Winter	5.76	1.54	1.85	7.83	29.64	30.44	37.65	12.53

Table 6. Segmentation of sand drift potential by wind in the desert areas (Fryberger & Dean, 1979)

Wind erosion potential	Amount of sand drift in terms of cubic meters per year within 1 m
High	33>
Moderate	33-17
Low	17<

In autumn, winter and spring seasons, the maximum velocity threshold for Ardestan station is from the southern and southwestern directions, while only in summer season it is from northern and northeastern directions. Furthermore, for Esfahan Station, the maximum velocity threshold of erosion and sand drift, mainly in winter and spring seasons, is from Southwest direction. Moreover, for Kashan station the maximum velocity threshold belongs to spring, autumn and winter seasons, from south and southwest directions. While, it is form east and southeast directions in summer season. Besides, this condition for Khour & Biabanak station is from the south and southwest directions, while in summer season it is from the north and north-east directions. Eventually, for Natanz station the maximum velocity threshold of erosion is from the west, south and southwest directions throughout entire the year (Table 5).

Quantitative values of displaced sand by various methods are shown in Table 7. The amount of sand drift is shown with QS in the table. According to classification by Fryberger and Dean (1979), in terms of Hsu and Kavamora formulas, Ardestān station is placed in the group with high erosion, but in terms of the Bagnold, Xing and Lettau lettau formulas, it belongs to middle class. Moreover, refer to Kavamora formula, Esfahan station is allocated to middle class erosion, while in all other formulas it is placed in low erosion group. According to classification by Fryberger and Dean (1979), and based on presented formulas, Kashan, Khour & Biabanak and Natanz Stations are placed in low erosion class.

For RQS, based on different empirical relationships, different values have been obtained. According to lettau lettau’s formula, the maximum value of this column belongs to Esfahan station (8.61 km/m/year), while the minimum value is obtained for Kashan station (0.65 km/m/year).

For DSF, with regard to different formulas, different values have been gained. For example, refer to lettau lettau’s formula, which is the software default, the greatest amount of displaced sand is for Esfahan station (25.1 t/m/y), while the lowest amount is for Khour&Biabanak station (7.94 t/m/y).

Table 7. The values of drifted sand based on empirical formulas (The results are based on the output of sand rose graph)

station	Method	QS (Kg/m.s)	TSF (kg/m.Year)	RQS (kg/m.s)	DSF (kg/m.Year)
Ardestan	Bagnold (1941)	13	37955.71	2.82	8237.34
	Zingg (1953)	10.11	29534.29	2.2	6409.68
	Kawamura (1964)	27.89	81424.24	7.15	20892.41
	Lattau & Lattau (1978)	16.58	48423.57	4.8	14016.85
	Hessu (1973)	17.41	50825.52	3.78	11030.41
Esfahan	Bagnold (1941)	7.35	21471.3	4.91	14343.57
	Zingg (1953)	5.72	16707.36	3.82	11161.09
	Kawamura (1964)	17.69	51654.42	12.55	36650.71
	Lattau & Lattau (1978)	11.77	34358.1	8.61	25155.61
	Hessu (1973)	9.85	28751.66	6.58	19207.1
Kashan	Bagnold (1941)	1.07	3126.31	0.44	1293.24
	Zingg (1953)	0.83	2432.66	0.34	1006.3
	Kawamura (1964)	2.19	6403.95	1.05	3070.27
	Lattau & Lattau (1978)	1.28	3747.71	0.65	1889.95
	Hessu (1973)	1.43	4186.36	0.59	1731.74
Khour & Biabanak	Bagnold (1941)	3.17	9242.24	1.94	5661.09
	Zingg (1953)	2.46	7191.61	1.51	4405.03
	Kawamura (1964)	6.42	18747.67	4.41	12870.5
	Lattau & Lattau (1978)	3.79	11078.99	2.72	7945.23
	Hessu (1973)	4.24	12376.04	2.6	7580.62
Natanz	Bagnold (1941)	4.81	14046.13	2.99	8732.36
	Zingg (1953)	3.74	10929.64	2.33	6794.87
	Kawamura (1964)	11.97	34942.42	8.34	24355.3
	Lattau & Lattau (1978)	8.5	24811.07	6.22	18160.85
	Hessu (1973)	6.44	18808.81	4	11693.28

4.3. The relationship between sand landforms migration pattern and the meteorological stations wind data

The processing results of satellite imagery and also the Erg stations wind data, indicate that A, D, F, and E zones have Northwest-Southeast direction. So, the Migration pattern is also in the same direction. Therefore, it seems that wind data results of Esfahan, Ardestān, Natanz and Kashan Stations have little impact on the dunes main trend, and can only have an impact on some irregularities in the shape of landforms. Furthermore, the wind data results of Khour & Biabanak Station, which is the nearest station to the Mesr Erg, demonstrate that Northwest winds are faster than the maximum velocity threshold of erosion. The sand rose pattern of this station matches with the Migration pattern of A, D, F, and E zones that has the Northwest-Southeast trend. Moreover, the Migration pattern of B and C zones is North-South and West-East, respectively. In this respect, the relocation pattern of zone C can also be attributed to the winds from West. Here, in addition to North–South direction, the landforms have also West-East Migration. In general, in those parts that the Migrations are mainly Northwest–Southeast, the Southwest drifting is also happened, but the wind energy is not enough to affect the general trend of the landforms Migration.

5. Discussion

Iran's central desert area has large masses of sand, including Jen Erg, Sargardan, Khartooran, Mesr and Chah-e-Jam, that have drawn many researches attention toward the study of their landforms (Mousavi et al., 2010; Mashhadi et al., 2007; Maghsoudi et al., 2013; Yamani, 2015). Additionally, results of previous studies in this area, illustrate that topographic and wind shelter factors of the Dasht-e Kavir landforms, have impact on sand dunes locating (Maghsoudi et al., 2013). Besides, according to Yamani (2015), spatial distribution of Dasht-e Kavir Erg dunes, in addition to the topography, has been influenced mainly by local pressure systems.

Morphological distribution of these sand dunes around the desert, is because of convergent winds, which dominated by thermal low pressure system during the warm period of the year. Also results of annual average of wind pattern, firstly, represent general direction of Northwest-Southeast, and secondly, East-West pattern. In the northern parts of the desert, winds have North–South direction, which mainly happen in the warm season of the year, which are found as a result of low pressure system in summer. Furthermore, in the cold seasons of the year Northwest-Southeast, and West-East trends are dominated, although, the general Migration trend of Mesr Erg prove it. As a whole, the results of this study on Mesr Erg surface, fit in other studies, which previously have been done there.

6. Conclusion

In this study, we tried using satellite imagery data and wind data of meteorological stations of Mesr Erg, the sand dunes Activity rate, dunes Migration pattern, and also factors affecting their intensity and patterns to be identified. The total area of the Mesr Erg is about 700 km^2. In addition, the general form of studied dunes are mostly the Barchans. In the first part, using detection techniques, the change rate in the time period of 2003 -2016 was extracted. However, class changes of sand dunes in two time periods in the studied region, approximately 29 km^2, were evaluated. This part was done just to provide an overview of regional shifting, because more detailed evaluation of sand dunes displacement using Landsat imagery is not possible. Besides, the general pattern of displacement in this section indicates the direction of movement mainly with trend of Northwest-Southeast. Finally to determine the displacements in the Erg region, six limited areas, which have had significant changes were selected. In this regard, 251 cases of sand dunes were measured. Moreover, the results have demonstrated the Migration of about 41 meters for the period of 2012 to late 2016. However, considering the results of wind data, seems Khour & Biabanak station, the closest station to the studied area, is closely fits the sand dunes relocation pattern.

To compare the results of this study with other studies, an attempt was done based on pressure patterns on the Erg surface, because of some irregularities in the sand dunes displacement pattern. Refering to the other researchers studies, which have been done based on pressure systems in the Dasht-e Kavir region, represent dominating the low pressure pattern in summer season. Therefore, convergent winds are pulled to the middle parts of the desert. So, that Erg activity in this area follows this cyclonic pattern, which result in irregularities in dunes Migration pattern to the Southwest direction. But in other seasons, following the general pattern of winds flow, the Migration direction is Northwest-Southeast.

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