Analysis of movement and relationships between morphometric components of sand dunes (barchans) in the south-eastern of Iran

Mehdi Feyzolahpour[1],[*], Rouholah Khodaie[1], Hasan Ghasemlu[2]

[1] University of Zanjan, Faculty of Humanities, Department of Geography, Iran
[2] University of Tabriz, Faculty of Planning and Environmental Sciences, Department of Geography and urban planning, Iran
[*] Corresponding author: feyzolahpour@znu.ac.ir

ABSTRACT

Morphology of barchan dunes plays a key role in the rate of movement of barchan dunes and accordingly, the areas that are in the path of barchan dunes can be identified. In this study, morphological parameters of eight barchan dunes in west Lut and movement were investigated. For this purpose, 8 parameters of windward slope length, back-to-wind slope length, right arm length, left arm length, length, width, right width and left width were measured in each barchan dune and Pearson correlation was calculated by SPSS software. In order to better understand the shape of barchan dunes, satellite images were extracted separately from google earth. The results of morphometry showed that barchan dune 6 was in the first place in terms of all morphometric factors. The right arm length to the width had the highest correlation (0.993). The back-to-wind slope length to the right arm length had the lowest correlation (0.815). The right arm length to the width had the highest coefficient of determination (0.9845). The movement during 2005–2019 was extracted from satellite images. It was found that until 2015, the highest movement belonged to barchan dune 3 (225.55 m) and during 2017–2019, the lowest movement belonged to barchan dune 6 (137.49 and 184.66 m). The highest movement during 2017–2019 was 288.24 and 307.67 m for barchan dune 5, respectively.

1. Introduction

About 80 million hectares of the Iranian plateau have very little vegetation and 12 million hectares are covered by barchan (Negaresh et al. 2008: 47). Different dune-like forms are found in deserts, which are classified into different groups by geologists. These depend on the amount of barchan available and the change in wind direction over the years (Brookfield et al. 2000; Bagnold 1941). The most well-known type of these shapes are barchan dunes, which are crescent-shaped and formed by the wind in the same direction over time. Barchan dune movement depends on wind speed and barchan dune height. The height of barchan dunes was between 1.5 and 10 m, while depending on the type, they were 40–150 m long and 30–100 m wide. Also, they have a slope between 8 and 20 degrees and lead to a sharp edge. This edge is located at the tip of the barchan dune and separates the sliding plate from the windward edge (Sauermann et al. 2000: 247). Barchan dune is one of the famous desert forms. These dunes cause deviating the wind due to their crescent shape. The factors affecting the crescent shape of barchan dunes follow nonlinear processes (Hersen 2004). Barchan dunes are formed in areas where there is not adequate barchan to completely cover the surface and the wind blows in the same direction for most of the year (Sauermann et al. 2003: 248). Barchan dunes are made of moving sand and move in the direction of the prevailing wind while maintaining their crescent shape. Therefore, movement is one of their most important features, so this obvious feature of barchan dune has turned it into a natural threat. Accordingly, it is necessary to pay attention to it as a risk factor. Although for more than

Tab. 1 Geographical location of eight barchan dunes in the study area.

Barchan number	Latitude	Longitude
Barchan No. 1	29° 59′ 49.55″ N	58° 07′ 05.97″ E
Barchan No. 2	29° 59′ 44.14″ N	58° 06′ 51.57″ E
Barchan No. 3	29° 59′ 40.63″ N	58° 06′ 57.34″ E
Barchan No. 4	29° 59′ 36.66″ N	58° 07′ 19.50″ E
Barchan No. 5	29° 59′ 33.52″ N	58° 07′ 29.89″ E
Barchan No. 6	30° 00′ 01.96″ N	58° 06′ 49.81″ E
Barchan No. 7	30° 00′ 05.11″ N	58° 07′ 05.30″ E
Barchan No. 8	29° 59′ 53.91″ N	58° 06′ 58.68″ E

50 years geologists and geographers have measured barchan dunes and obtained data on their height, width, length, volume and movement rate, little is known about the morphological features of barchan dunes (Wiggs et al. 1996: 34). From a mathematical point of view, some are symmetrical shapes that are formed in the direction of the wind, but in nature, some factors such as unstable wind speed or the slope of the earth lead to their asymmetry. Simulations have also been performed to predict the evolution of barchan dunes (Howard and Morton 1978; Wippermann and Gross 1986; Anton and Vincent 1986; Anthonsen et al. 1996). Bagnold (1941) and Finkel (1978) presented the first concepts on barchan dunes and their morphological relationships in southern Peru. Then, many studies have been conducted on the morphology and movement of barchan dunes around the world (Lettau et al 1969; Ting Wang et al. 2007; Hesp et al. 1998; Gay 1999; Al-Harthi 2002; Daniell et al. 2007; Valle et al. 2008; Belrhiti et al. 2011; Hamdan
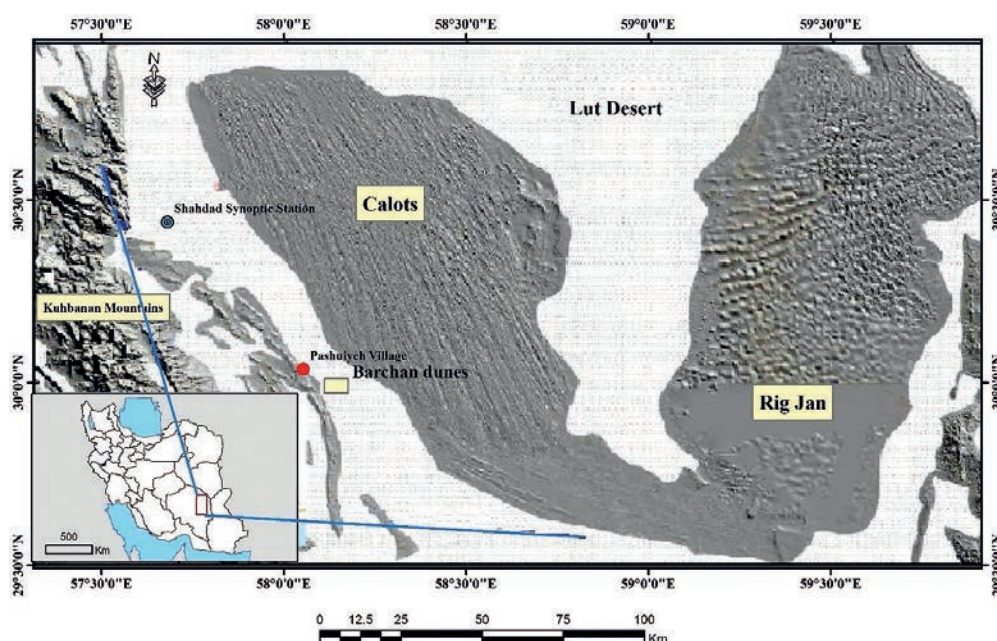

Fig. 1 Location of barchan dunes studied.

et al. 2015, 2016; Al Mutiry et al. 2016; Michel et al. 2018; Fu et al. 2019; Hu et al. 2019; Abdelkareem et al. 2020). In Iran, several studies have been conducted on the morphology of barchan dunes, especially barchans (Negaresh et al. 2008; Maghsoudi et al. 2018a, 2018b).

Barchan dune is one of the most common desert forms caused by the accumulation of barchan particles and wind erosion. According to the above, in this study, according to eight barchan dunes located in west Lut, the morphometric features, the relationships between them and the extent of their movement
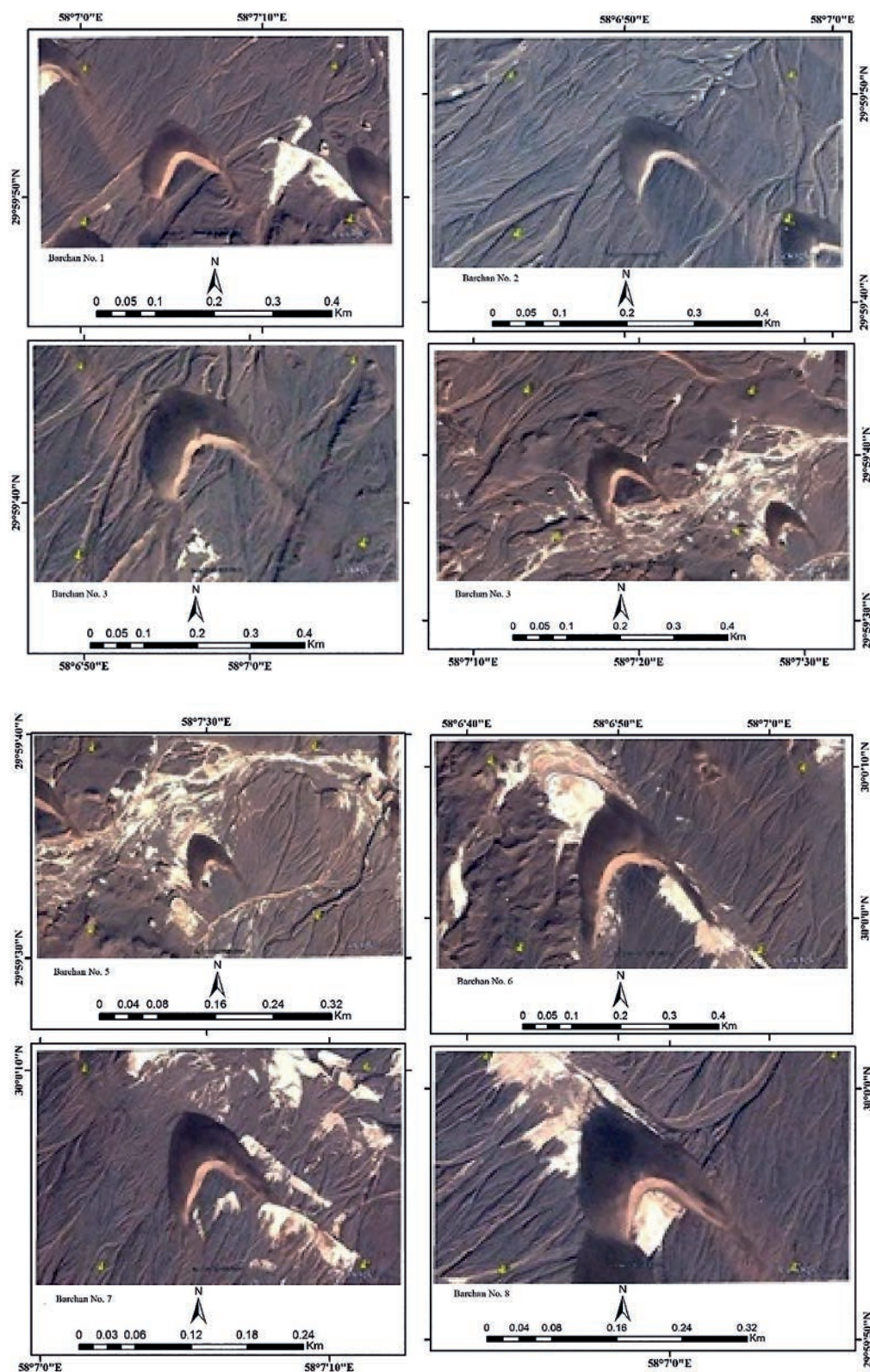

Fig. 2 Location of barchan dunes studied in Google earth image.

during 2005–2019 have been analyzed. It should be noted that Maghsoudi et al. in two studies investigated the morphometry of barchan dune and the movement of Pashuiyeh in west Lut, and the study area in this study is the same area in the study by Maghsoudi et al. However, the period studied for estimating the movement in the study by Maghsoudi et al. (2018a) was 1967–2005, while in the present study, the period 2005–2019 was investigated and it was attempted to complete the study by Maghsoudi (2018a). For the analysis of morphometric parameters of Barchan dune, Maghsoudi et al. (2018b) examined seven Barchan dunes in Pashuiyeh, which were different from eight barchan dunes in this study in Pashuiyeh. The novelty of this study is that so far, few studies have been conducted in the field of morphology and movement of barchan dunes in Iran and this study is one of the new studies in this field. Given that this region is newly registered as a natural monument in UNESCO cultural heritage, so the introduction of its features is very important.

2. Study area

The studied barchan dunes are located in Pashuiyeh village in Kerman Province and east of this city. This village is located at an altitude of 360 m above sea level. The barchan dunes are located to the east of Pashuiyeh village, and to the west are sediments from the Pleistocene.

3. Methodology

In this study, using google earth images, eight barchan dunes were identified in west Lut and Pashuiyeh
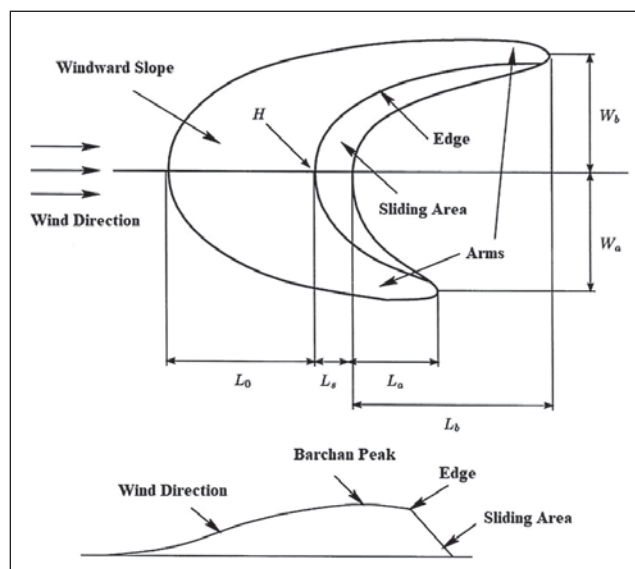

Fig. 3 Parameters used in morphometry of barchan dunes (Sauermann et al. 2000).

village and were used as target barchan dunes in the analysis of morphometric relationships between certain parameters. In order to measure the length and average width of the barchan dunes, satellite images downloaded from google earth and during 3 days, the height of the barchan dunes was measured using GPS. In this way, first the absolute height of the area was measured by GPS and then the difference in height of the mentioned point with the barchan dune peak was measured. The morphometric parameters of barchan dunes included windward slope length (Lo), back-to-wind length (LS), right arm length (La), left arm length (Lb), length (L), width (W), left width (Wb) and right width (Wa). The position of the above parameters is shown in a schematic of barchan dunes.

Among the above parameters, only the calculation of two parameters of length and width of barchan dunes requires the use of the following equations. This equation is also used to calculate the width of barchan dunes:

$$L = Lo + Ls + (La + Lb)/2$$

In this equation, La is the length of the right arm, L is the length of the barchan, Lo is the length of the windward slope, Lb is the length of the left arm, and Ls is the length of the leeward slope. This equation is also used to calculate barchan width:

$$W = Wa + Wb$$

In this equation, Wa is the right width and W and Wb are the barchan width and the left width. After estimating the above morphometric parameters, the relationship between the components was calculated using Pearson correlation by SPSS software and finally the values of coefficient of determination (R^2) were estimated by Origin 8 software and the wind direction and speed were drawn for the study area. Finally, using satellite images, the movement of the barchan dunes was measured during 2005–2019. In order to investigate the movement the barchan dunes, satellite images of google earth have been used. In this way, the images of 2005, 2017 and 2019 were first downloaded in digital form and by Arc GIS, the barchan dunes were drawn from the images.

4. Results and discussions

In this study, the morphometric properties of eight barchan dunes were measured and the morphometric components of windward slope, back-to-wind slope, right arm length, left arm length, length, width, left width and right width were estimated. Barchan dune 6 had the highest windward slope length (96.44 m) and Barchan dune 1 had only 28.93 m of windward slope length. Barchan dune 8 was in the second place in terms of the windward slope length (71.98 m). The

Tab. 2 Morphometric parameters calculated in eight studied barchan dunes to meter.

| Row	Length of windward slope (Lo)	Length of leeward slope (Ls)	The length of the right arm (La)	The length of the left arm (Lb)	Length (L)	Width (w)	Left width (Wb)	Right width (Wa)
1	28.93	9.82	28.28	39.02	75.02	72.54	34.72	37.84
2	57.29	8.32	39.56	62.96	107.89	84.56	38.77	45.79
3	39.46	7.78	24.64	38.57	74.59	54.71	21.60	33.11
4	61.27	12.83	45.20	64.52	122.8	97.41	37.43	59.98
5	43.47	9.90	30.53	43.23	83.96	61.39	24.25	37.14
6	96.44	16.50	108.42	157.15	208.30	190.73	84.79	105.94
7	43.35	6.41	29.23	54.69	83.99	68.46	31.86	36.60
8	71.98	10.51	30.71	57.36	113.98	62.98	31.08	31.90

difference in windward slope length between these 8 barchan dunes was significant and about 43.05 m. Also, Barchan dune 6 had the highest back-to-wind slope length (16.5 m). Barchan dune 7 had the lowest back-to-wind slope length (6.41 m). Barchan dune 4 was in second place in terms of back-to-wind slope length (10.51 m). Barchan dune 6 had the highest right arm length (108.42 m) and Barchan dune 3 had the lowest right arm length (24.64 m). A significant difference was between the highest right arm length and the second one, which was for Barchan dune 4 (45.20 m). The reason for this is not clear, but this difference is more than double. In the meantime, it is observed that the differences in the right arm length were very close among other barchan dunes. This can be considered as an exception. Barchan dune 6, which was in the top position among 8 barchan dunes in terms of other morphometric components, was also in the first place in terms of the left arm length (157.15 m). Barchan dune 3 has the lowest left arm length (38.57 m). The exceptional width of Barchan dune 6 is still visible in the left arm length. For the length, which was calculated from the equation of the right and left arm length, Barchan dune 6 had the highest length (208.3 m). Barchan dune 3 had the lowest length (74.59 m). Barchan dune 3 had the lowest left width (21.6 m). Also, Barchan dune 6 had the highest width. Barchan dunes 1, 2, 4, 7 and 8 had very close values, but Barchan dune 6 had a significant difference in all morphometric parameters. Barchan dune 3 had the lowest width and Barchan dune 6 had the highest width (105.9 m). It can be said that almost all barchan dunes except Barchan dune 6 had the same right length relative to each other. For the width, which is obtained from the equation of left and right width, Barchan dune 6 had the highest width (190.7 m) and Barchan dune 3 had the lowest width (54.7 m).

In order to measure the wind direction and speed in the study area, the data of Shahdad synoptic station, which is 60 km away from the study area, had been used. The location of this station is shown in the map of the study area. The windrose diagram shows that most of the wind that blows in the study area has a speed of more than 11 meters per second and blows from the north. This explains the direction to the south of the barchan dunes.

In order to calculate the correlation between the barchan dune components, SPSS software and Pearson correlation method were used, the results of which are shown in Table 3. According to the data displayed in the Table above, the following results were obtained:

The windward slope length along with the length had the highest correlation (0.958). The back-to-wind slope length along with the length had a high correlation equal to 0.881. The right arm length had a high correlation of 0.993 and the left arm length had a correlation of 0.989. Also, the length along with the left arm length had a correlation equal to 0.977.
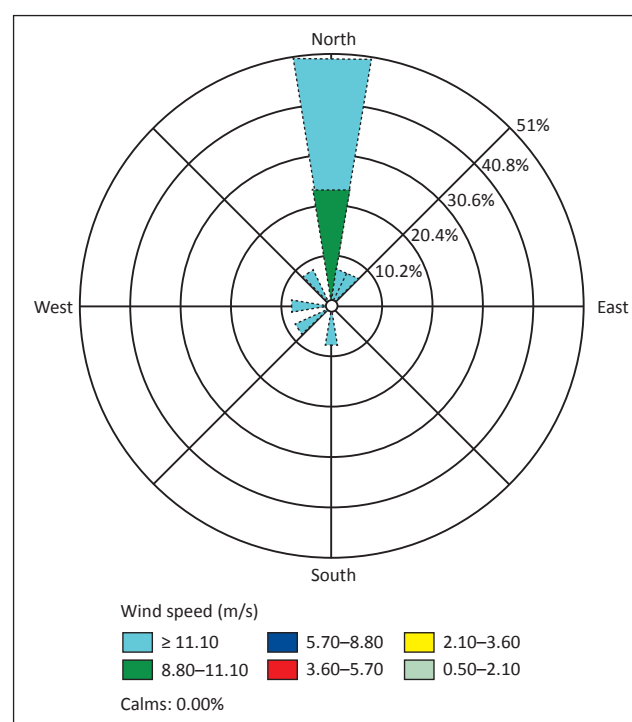
Fig. 4 The windrose diagram in the study area.

Tab. 3 Values of Pearson correlation between the factors used.

		Lo	Ls	La	Lb	L	Wa	Wb	W
Lo	Pearson Correlation	1	.858**	.873**	.900**	.958**	.825*	.875**	.856**
	Sig. (2-tailed)		.006	.005	.002	.000	.012	.004	.007
	N	8	8	8	8	8	8	8	8
Ls	Pearson Correlation		1	.859**	.815*	.881**	.872**	.816*	.856**
	Sig. (2-tailed)			.006	.014	.004	.005	.014	.007
	N		8	8	8	8	8	8	8
La	Pearson Correlation			1	.989**	.966**	.986**	.979**	.993**
	Sig. (2-tailed)				.000	.000	.000	.000	.000
	N			8	8	8	8	8	8
Lb	Pearson Correlation				1	.977**	.959**	.977**	.977**
	Sig. (2-tailed)					.000	.000	.000	.000
	N				8	8	8	8	8
L	Pearson Correlation					1	.943**	.943**	.952**
	Sig. (2-tailed)						.000	.000	.000
	N					8	8	8	8
Wa	Pearson Correlation						1	.960**	.992**
	Sig. (2-tailed)							.000	.000
	N						8	8	8
Wb	Pearson Correlation							1	.987**
	Sig. (2-tailed)								.000
	N							8	8
W	Pearson Correlation								1
	Sig. (2-tailed)								
	N								8

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

It was also observed that the right width along with width had a correlation of 0.992 and the width along with the right arm length had a correlation of 0.993. In the meanwhile, the windward slope length along with the right width had a slight correlation equal to 0.825 and the back-to-wind slope length along with the right arm length had a correlation equal to 0.815. Also, the right arm length along with the back-to-wind slope length had a correlation of 0.859. The correlation between the left arm length and the back-to-wind slope length was equal to 0.815. Finally, the correlation between length and back-to-wind slope length; right-width and windward slope length; left-width with back-to-wind slope length, and width and windward and back-to-wind slope length was 0.881, 0.825, 0.816 and 0.856, respectively. The results of Pearson correlation showed that the highest correlation of 0.993 was observed between the width and the length of the right arm and the lowest correlation was observed between the back-to-wind slope length and the left arm length.

The values of coefficient of determination (R^2) were estimated for 7 factors with the highest correlation as follows. According to the obtained values, it is observed that the highest coefficient of determination (0.9845) belongs to the width and length of the right arm and the lowest coefficient of determination (0.7666) belongs to the length of the back-to-wind slope length. The relationship between width and left width (0.9813) in terms of the highest coefficient of determination was in the second place. At this stage, using the parameters mentioned in the relevant Table, the regression equation was calculated among the factors that had the highest correlation and coefficient of determination with respect to each other.

Using the components of mean, standard deviation and Pearson correlation coefficient, the linear regression equation was calculated between the factors that had the highest correlation with each other. The above values are shown in the Table below.

Finally, the movement of barchan dunes was calculated during 2005–2019. The reason for using these time periods was the adaptation of the Gregorian calendar data with the solar calendar in Iran. In addition, the special attention of state officials in matters related to villages during these periods has led to an emphasis on these years. Studies have shown an inverse relationship between movement rate and the
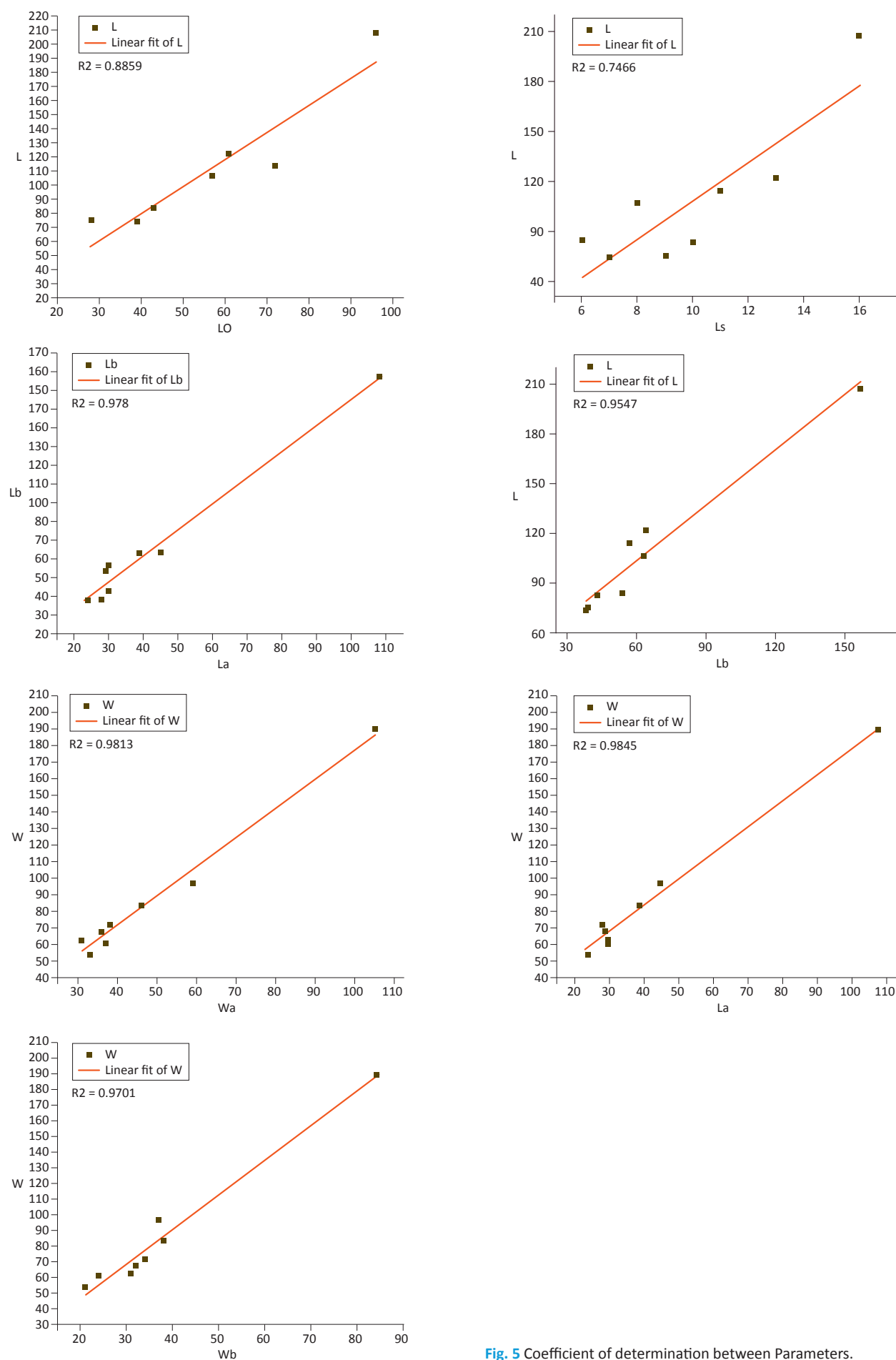
Fig. 5 Coefficient of determination between Parameters.

Tab. 4 Statistical values of components used for morphometric analysis of barchan dunes.

Statistical parameters	Minimum	Maximum	Total	Average	Standard deviation	Variance	Skewness	Kurtosis
Lo	39.46	96.44	459.48	57.4350	19.23524	369.994	1.331	1.505
Ls	6.41	16.50	81.97	10.2463	3.17907	10.106	1.085	1.282
La	24.64	108.42	336.57	42.0713	27.61851	762.782	2.523	6.631
Lb	38.57	157.15	517.50	64.6875	38.74336	1501.048	2.438	6.393
L	74.59	208.30	870.53	108.8163	44.18772	1952.555	1.939	4.221
Wa	31.90	105.94	388.30	48.5375	24.88598	619.312	2.199	4.985
Wb	21.60	84.79	304.48	38.0600	19.80148	392.099	2.314	5.988
W	54.71	190.73	692.78	86.5975	44.24161	1957.320	2.332	5.794

Tab. 5 Pearson correlation coefficient, determination coefficient and regression equations of barchan dunes.

Correlated factors	Pearson correlation coefficient	Coefficient of determination	Regression equation
Lo and L	0.958	0.8859	Lo = 0.41 L + 12
Ls and L	0.881	0.7466	Ls = 0.06 L + 3.46
La and W	0.993	0.9845	La = 0.6 W − 10.4
La and Lb	0.989	0.9780	La = 0.7 Lb − 3
L and Lb	0.977	0.9547	L = 1.13 Lb + 36.6
Wa and W	0.992	0.9813	W = 1.74 Wa − 2.2
Wb and W	0.987	0.9701	W = 2.17 Wb + 3.5
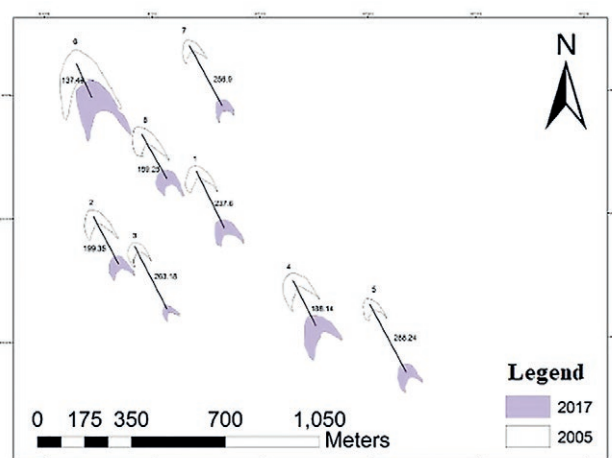
Fig. 7 Barchan movement rate from 2005 to 2017.
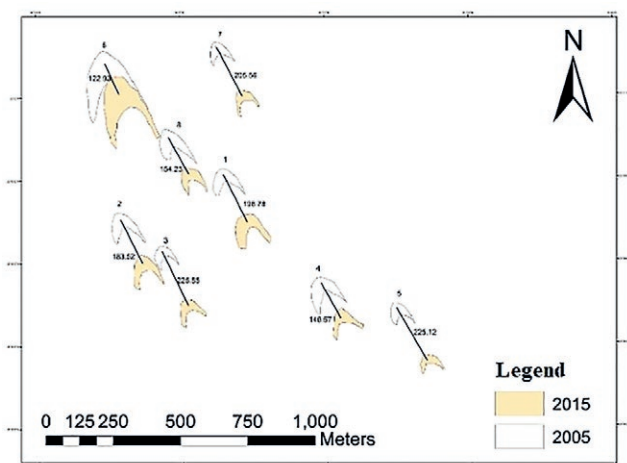
Fig. 6 Barchan movement rate from 2005 to 2015.
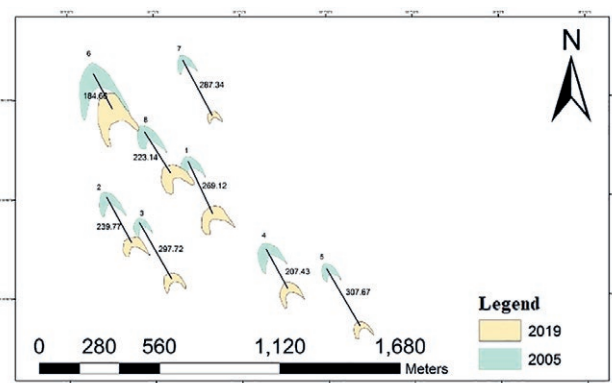
Fig. 8 Barchan movement rate from 2005 to 2019.

size of the barchan dune. The movement values for each barchan dune during the period mentioned in the Table are displayed and extracted from satellite images.

5. Conclusion

The study area is located west Lut. This area is the main place of density of barchan dunes in west Lut.

In this study, the morphometric factors of barchan dune 8 have been investigated. First, the morphometric properties of the barchan dunes such as slope length were analyzed and then Pearson correlation was calculated for these factors by SPSS software. Finally, after estimating the coefficient of determination, the regression equation was estimated for the factors that had the highest correlation. According to the results of the measurements of barchan dunes, it was found that a significant difference was

Tab. 6 Movement of barchan dunes since 2005 to 2015, 2017, and 2019.

Row	The rate of movement from 2005 to meters	Barchan No. 1	Barchan No. 2	Barchan No. 3	Barchan No. 4	Barchan No. 5	Barchan No. 6	Barchan No. 7	Barchan No. 8
1	The rate of movement to 2015	198.78	183.52	225.55	148.57	225.12	122.93	205.56	154.23
2	The rate of movement to 2017	237.60	199.35	263.18	188.14	288.24	137.49	256.90	189.28
3	The rate of movement to 2019	269.12	239.77	297.72	207.43	307.67	184.66	287.34	223.14

in the size of the components of barchan dunes relative to each other. In the meantime, Barchan dune 6 among 8 barchan dunes studied had the highest windward slope (96.44 m). The same barchan dune had the highest back-to-wind slope (16.5 m). The longest right arm was 108.42 m for Barchan dune 6. The right arm length was significant compared to the other 7 barchan dunes, so that in some barchan dunes it even reaches five times. The same barchan dune had the highest left arm length (157.15 m). Barchan dune 6 had the highest length (about 208.3 m). Also, Barchan dune 6 had the highest width, and left and right width (190.73, 84.79 and 105 m). According to the calculation of Pearson correlation between the parameters, it is observed that the left arm length and width has the highest correlation (0.993) and the back-to-wind slope length and width had the lowest correlation (0.815). At the next stage, the coefficient of determination was calculated for the parameters that had the highest correlation. The results showed that the right arm length to the width had a coefficient of determination equal to 0.9845. This was the highest among other factors. Finally, regression equations were estimated for the cases where the coefficient of determination was calculated. The rate of movement during 2005–2019 was extracted from satellite images. It can be seen that until 2015, the highest movement belonged to Barchan dune 3 (225.55 m) and the lowest movement belonged to Barchan dune 6 (122.93 m). During 2017–2019, the lowest movement belonged to Barchan dune 6 (137.49 and 184.66 m) and during 2017–2019, the highest movement belonged to Barchan dune 5 (288.24 and 307.67 m). Therefore, it was observed that during 2015–2019, the rate of movement in Barchan dune 6 has increased significantly.

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