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New method for measurement of barchans parameters Case study: Lut desert, Iran

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Abstract

This research has attempted to measure the parameters of barchan dunes as one of the desert landforms. This has been conducted by a field survey using cartographic techniques. In the field, two barchan dunes have completely been surveyed by total station equipment. Using the sample points a novel method has been devised to measure the barchans parameters. The method is mainly based on geometric relations and Cartesian coordinate system. All the parameters of the dunes have been measured by both the common methods of previous studies and the new method of this study. By this research, some new parameters have also been added to the dune analysis studies. The method has proved to be more precise relative to the previous methods for measurements of barchans. These measurements make it possible to compare the dunes in different areas of the world and also for different periods of time. Many parameters of the dunes can also be examined more easily.

Keywords: Barchan; Surveying; Sand dune; Lut desert

1. Introduction

There is a variety of desert landforms in Lut Desert, Iran. Barchan dunes with crescent shapes can be found in deserts (Hesp and Hastings, 1998; Dong *et al.,* 2000; Sauermann *et al.,* 2000; Wang *et al.,* 2007; Besler, 2008; Elbelrhiti, 2012), coastal areas (Gay, 1999; Ghahroudi *et al.,* 2012), on bed of the seas (Todd, 2005; Burrough *et al.,* 2012; Daniell, 2007), and also on the planet of Mars (Tanguchi and Endo, 2007; Boorke and Goudie, 2009; Zeng, 2009). The morphologies of barchan sand dunes as crescent shapes are controlled mainly by sand characteristics and wind regime over an area (Elbelrhiti, 2005; Hesp and Hastings, 1998; Dong *et al.,* 2000, Sauermann *et al.,* 2000; Elbelrhiti, 2012; Dong *et al.,* 2014). Unidirectional winds and limited supply of sand over un-vegetated lands (Elbelrhiti, 2012; Wang *et al.,* 2007; Sauermann *et al.,* 2000; Jiang, 2013) make a field with many forms of barchan dunes in the arid area of Dashte Lut. These shapes cover large areas in desert regions of the world.

Barchans are found mainly in arid areas which are greatly under the threat of desertification. These areas cover 40% of land of which 66% are already affected. All continents are affected: 37% of drylands are in Africa, 33% in Asia, 14% in Australia and some are also found in America and the southern fringes of Europe (The French Scientific Community on Desertification, 2013). Observing barchans with similar peculiarities in the earth and Mars, it would be possible to understand the same processes on the Mars (Taniguchi and Endo, 2007; Bourke and Goudie, 2009). Researches about barchans have implications for paleo-environmental studies (Hesse, 2009) and control systems of sands (Dong *et al.,* 2000; Navarro *et al.,* 2011) and about the origins of sand storms (Ghahroudi and Nezammahalleh, 2012) and their prediction (Rashki *et al.,* 2013). The hazard of dynamic dunes (Liu *et al.,* 2005) can affect the life of indigenous people (Maghsoudi *et al.,* 2013). Therefore, it is important to know the geomorphologic properties and behaviors of these dunes particularly in areas like south east of

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The morphological characteristics of barchans are affected by many factors including height, width, and length (Howard *et al*., 1978; Elbelrhiti *et al.,* 2008; Sauermann *et al.,* 2000; Ehsani and Guiel, 2009; Burrough *et al.,* 2012;) that control their dynamic behaviors (Liu *et al.,* 2005; Besler, 2008; Mashhadi *et al*., 2008). In this study, we have studied the parameters in morphology of barchans in Shahdad, west of Lut Desert, and suggested a somewhat modified model to measure these parameters. As there are no similar applications of geometric principles for measuring barchan parameters in previous studies, we have initially defined the parameters by geometric basics.

Hesp and hastings (1998) verified the relationships between the width, height, and shape of barchans dunes (Sauermann *et al.,* 2000). They found that the morphology of the dunes is proportional to the height and width and under the control of aerodynamic processes, as this later was also stated by Elbelrhiti (2005). The two parameters have direct linear relationship and there is a constant feedback among the three dimensional windward shapes, leeward slope, and the width between the two horns (Hesp and Hastings, 1998; Daniell and Hughes, 2007). Monitoring the dynamics of barchans dunes in Taklimakan Desert, Dong *et al*. (2000) measured the morphometric parameters of the dunes and examined the relationship of these parameters and with wind regimes and the dune migration. Sauermann *et al*. (2000) emphasizing the elevation points outlined a model to explain the differences in barchans. The barchans have elevation from 1.5 to 10 meters, base from 40 to 150 meters, and width from 30 to 100 meters with a parabola shape. Todd (2005) investigated the submarine barchans in Canada and stated that the flows with higher power and speed can induce the dunes. Wang *et al*. (2007) confirmed that slip face of barchans is proportional to the width of horns. Many morphological forms of barchans were classified by Bourke and Goudie (2009) using satellite images in the Namib Desert and Mars. They classified those dunes into types of slim, normal, pudgy, and fat. They also found them as a function of grain particle size, wind speed, saturation of sands, and wind variations.

1.1. Study area

The study area is located on the west of Dashteh Lut near the city of Shahdad in an arid area. The geomorphologic forms of the area, about 320 km^2, are influenced by the winds in a direction from northwest towards southeast, as stated by Ehsani and Quiel (2007) and Oliphant *et al*. (2011). The average wind speed is 6m/s (Ehsani *et al.,* 2007) while the maximum is up to 10 m/s (Oliphant *et al.,* 2011) and the strong winds starts from April with about 9 m/s in the same direction known as Wind of 120 days (Ehsani and Quiel, 2007). The annual rainfall is less than 10 mm. The desert is located in the Middle East with solar irradiance of 950 W/m2at the peak (Nezammahalleh *et al.,* 2010). The average mean daily temperature is ranged from 11 degrees Celsius in January to 40 degrees Celsius in July that make the desert as the hottest points of the world (Ehsani and Quiel, 2007). The study area is in the east of Shahdad fold and thrust belt mainly with Neogene detrimental and evaporative deposits and gypsiferous marl and conglomerate (Mohajjel, 2009). Desertification is increasing from these areas towards the surrounding (Oliphant *et al.,* 2011). In the north of the area hundreds of barchans are forming and moving towards the south in a northwest to southeast direction with average speed of 20 m/yr (Maghsoudi *et al.,* 2013) (Fig. 1).

2. Materials and Methods

In this study we have used survey camera, Total Station, and GPS for mapping the parameters of two barchans in the study area. In cases where the survey camera is not available, it can also be possible to measure the parameters by GPS and inclinometer. The measurement of barchans can be performed by recording the coordinates of five points in the tips of both horns (p1, p2), the turning point at the line of base in the leeward (p3), the point of brink (p4), and the toe of the windward side (p5) (Fig. 2 and Fig. 3). The coordinates of other points on both the dunes have been recorded by survey camera. These points have been imported on a Cartesian coordinate system in order to measure the parameters with up to 155 and 115 points for the first and the second dunes, respectively.

2.1. Barchan geometric parameters

The parameters of barchans in this study include height of peak (Hp), the maximum height (Hmax), the maximum length (Lmax), the minimum length (Lmin), the total width (W), the right width (WR), the left width (WL), the distance of right length (DR), the distance of left length (DL), the length of windward face (FF), the length of leeward face (FB), the slope of windward face (Θ_F), the slope of leeward face (Θ_B), the mass (M), the volume (V), the area of windward or forward (AF), the area of leeward or backward (AB), the curvature coefficient of right and left horns (C_L, C_R), the ratio of AF to AB (RV), and the ratio of Lmin to Lmax (RL) (Table 1) (Fig. 2 and Fig. 3). We have used Hmax, CR, CL, RA, and RL for the first time in this research. In the following, we have measured the parameters of barchans both using previous measurements and by the five points (FP) method of this study. The way by which the parameters are measured has been explained in Table 1.

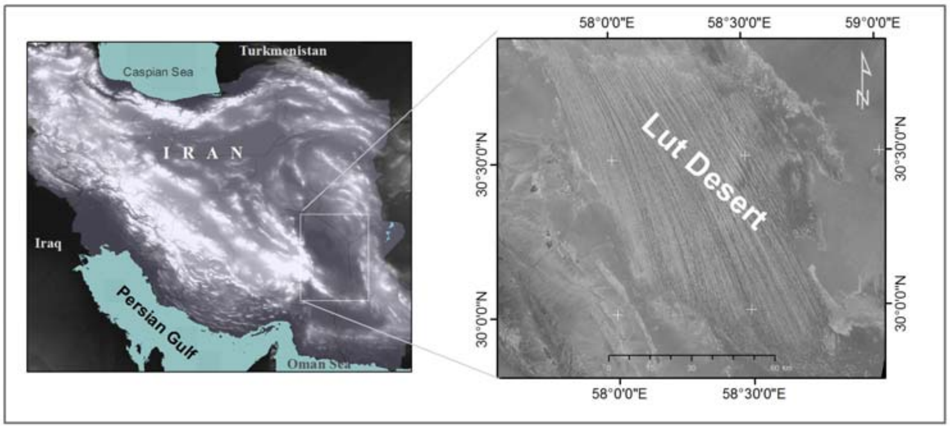

Fig. 1. Location of the study area, Lut Desert

Table 1. The parameters of barchans

Parameter	Definition in previous studies	Definitions in this study	Measurement
Height of peak	Vertical distance between base and peak	Vertical distance between p3 and p4	(H_P)
Maximum height	--	Maximum height of dune	(H_{Max})
Width	The distance between two horns	Same as previous, the distance between p1 and p2	W
Width of right and left	--	Distance from p1 and p2 to the intersection with the line crossing p3 and p4	(W_R) and (W_L)
The maximum length	Distance between end of longer horn and end of dune	Distance from the toe and the longer horn	L_{Max}
The minimum length	Distance from end of dune to shorter horn	Distance from toe to the shorter horn	L_{Min}
The length of right and left horns	Curved distance from end of horns to crossing line of brink and base	Curved distance from the end of horn and the mid-point of the crossing line of p3 and p5	(D_R) and (D_L)
Area of forward (stoss side)	--	the area surrounded by the curved line that connect p1, p5, p2 and p4 encompassing all dune area in stoss side.	A_F
Area of backward (slip face)	--	The sector resulted from the crossing line of p1 and p2 and the line of base in leeward	A_B
Curvature of left horn	--	Ratio of horizontal line between p1 and p3 to the length of horn	$C_L = \frac{\bar{d}_{1,3}}{D_L}$
Curvature of right horn	--	Ratio of horizontal line between p2 and p3 to the length of horns	$C_R = \frac{\bar{d}_{2,3}}{D_R}$
The curved length of stoss side	Horizontal distance from brink to toe	The curved distance from p4 to p5	F_F
The curved length of slip face	The horizontal line from brink to the base	The curved distance from p4 to p3	F_B
Slope of slip face	Slope between the brink and base	Slope between p3 and p4	Θ_B
Slope of stoss side	Slope between brink and toe	Slope between p4 and p5	Θ_F

2.2. Barchans parameters in the previous studies

An ideal barchan is symmetrical along the direction of prevailing winds, but in nature barchans are asymmetrical due to winds of different directions, sand particle properties, and slope of the surface (Elbelrhiti *et al.,* 2005; Sauermann *et al.,* 2000, Todd, 2005). The height of barchan dunes is usually one tenth of the width (Todd, 2005), the orientation of longitudinal axis is along the direction of wind and the height of steep slope in the slip face is defined as the vertical height from the base to the brink at the intersection of longitudinal axis with brink (Elbelrhiti *et al.,* 2008, Hesp and Hastings, 1998, Burrough *et al.,* 2012, Daniell and Hughes, 2007, Sauermann *et al.,* 2000) (Fig. 3).

2.3. Barchans parameters based on FP Method

The fundamental in this method, as a modification to the previous measurement methods, is that we have to define the dunes on a Cartesian coordinate system. To do so, it is required to have origin, X-axis, and Y-axis for the system. One of the axes must be the transverse line in the dune and the other must be drawn proportional to the dune so that the origin is one of the five points where intersect at the cross line. Obtaining the coordinates of the five points at the tip of right horn (p1), tip of left horn (p2), the turning point of line in the base on the leeward (p3), the brink point (p4), and the toe at the end of windward side (p5) relative to the origin, it is possible to model readily the whole barchan dunes. Thus, it is possible to compare the dunes in all the regions and also their dynamics over the time.

2.4. Coordinate system for barchans

2.4.1. Symmetrical barchans

In a symmetrical barchan, the X-axis, the line crossing the base, brink, and the toe of the dune, divides the dune into two equal sections. The origin is at p5, i.e., the turning point at the end of dune in windward, and the Y-axis is perpendicular to the X-axis at the origin (Fig. 2).

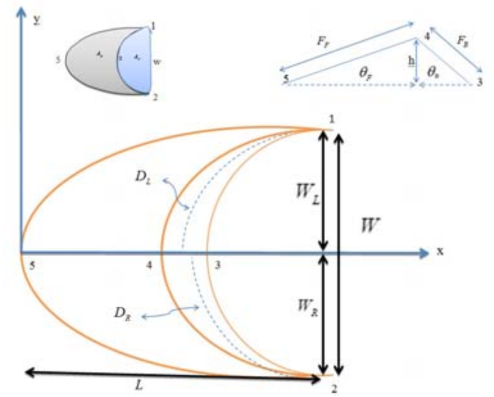

Fig. 2. The geometry of symmetrical barchans (Sauermann *et al*., 2000; Todd, 2005)

2.4.2. Asymmetrical barchans

In asymmetric barchans, nearly all the dunes in the nature (Zeng, 2009), the length of the couple of horns and also the width on the left and the right are not equal. They do not occupy equal space in both sides of X-axis. The parameters must be measured in both sides on the coordinate system. This model can easily be applied for asymmetric barchans.

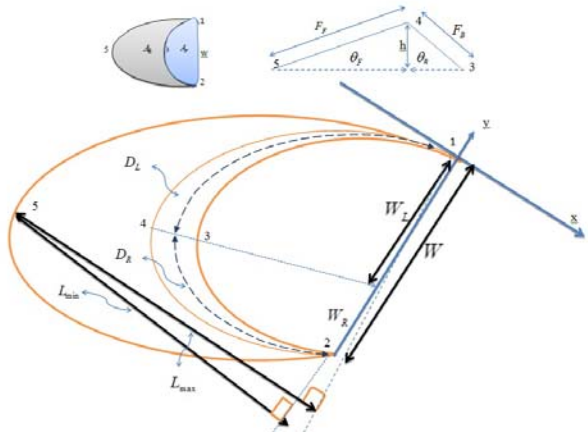

Fig. 3. The schematic geometry of asymmetrical barchans by FP method as designed by authors based on experimental observations

To calculate the parameters, the coordinate system must be defined relative to the five points. The X-axis is oriented along the movement of dune and the Y-axis is a right angle to that. After the five points are marked, for measuring the widths it is required to draw a straight line to connect the points of p3 and p4. The line cut the Y-axis into two segments and has an intersection with the line resulted from linking p1 and p2 (Y-axis). From the intersection the width can be measured in both sides. To calculate the Lmax and Lmin, a straight line must be drawn from p5 along the direction of movement perpendicular to the line from p1 and p2. The distance between the p5 and the intersection of p1 and p2 with p5 gives the Lmax and Lmin for an asymmetric dune.

To measure the AF and AB of the dune, we need to draw precisely both the area of whole dune and the area embraced by the horns. The area drawn from a hypothetical line between the end of the couple of horns (p1 and p2) and the concave line in the bottom of the slip face gives AF of a dune. The area within the concave line and the perimeter of dune gives AB of a dune. The horizontal area is taken for AF in the study.

3. Results

The calculation of barchan parameters are presented here according to both the usual way and the FP model of this study. The field measurements can either be carried out by cartographic camera or simple meter tool, inclinometer and GPS.

As represented in Tables 2 and 3, the height of dune is the same in both the usual way (Sauermann *et al.,* 2000; Todd, 2005; Burough *et al.,* 2012) and FP Method, but in FP the maximum height is used for analyses. The W is the same in both, but the WR and WL are different. The length in previous studies is just one value but by FP two length of small and large are measured. By these two lengths available, the direction and dynamics of the dunes can be modeled proportional to the wind speed and other characteristics (Herrmann and Sauermann, 2000). The FP has calculated AF and AB based on which the dunes can either be classified easily in any area or improve other classifications (Bourke and Goudie, 2009). The RV and RL have been calculated, the parameters by which the investigation of the dunes dynamics (Liu *et al.,* 2005) and vulnerabilities (Ghahroudi *et al*., 2012) can be enhanced. The curved length of horns is calculated instead of a straight line (Sauermann *et al.,* 2000, Burough *et al.,* 2012). (Tables 2 and 3).

Table 2. Calculation of barchan parameters according to common way in the previous studies

Parameter	Barchan I	Barchan II
Height	1.65	2.70
W	26.50	39.00
WL	13.50	15.50
WR	13.00	23.50
L	52.00	76.00
DR	4.00	9.00
DL	3.00	7.50
FF	39.00	61.00
FB	2.90	5.00

Table 3. Calculation of barchans parameters based on FP Method

Parameter	Barchan I	Barchan II
Height	1.65	2.70
Lmax	1.67	3.80
W	26.50	39.00
WL	10.50	14.50
WR	16.00	24.50
LMAX	52.00	76.00
LMIN	41.00	74.50
DR	14.50	27.00
DL	16.00	18.00
Θ_B	15	20
Θ_F	57	97
FF	44	73
FB	3.4	5.5
C_R	0.97	0.96
C_L	0.99	0.95
$A_B^{m^2}$	927	4300
$A_F^{m^2}$	92.5	230
R_V	10	119
R_L	0.79	0.99

The shape of the two dunes as sampled by survey can be seen in Fig. 4. This hillshade map clearly shows the situation of the crescent forms.

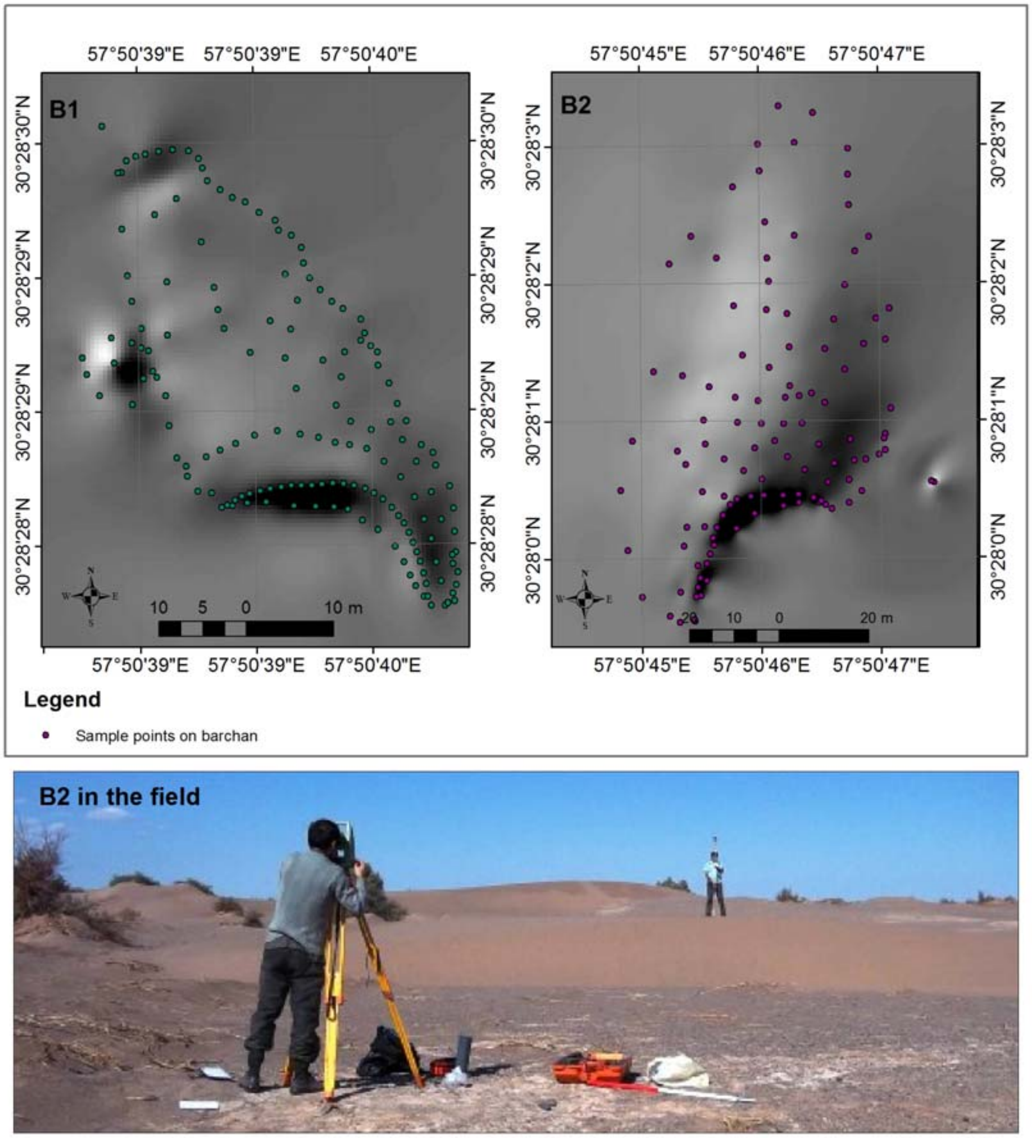

Fig. 4. Sample points on the two barchans as Surveyed by mapping camera (Total Station equipment); the dunes are illustrated by hillshade effects; the lower part shows the authors surveying in the field

4. Results and Discussion

The capabilities of proposed method in measurement and calculation of barchan parameters have been assessed in this research which has been conducted in a hyper-arid area with lots of dunes available in special fields around the Lut Desert. These dunes here have dynamics over time (Maghsoudi *et al.,* 2013) and their morphometric properties are influenced by wind regime with “wind of 120 days” (Ehsani and Quiel, 2007) that move sand particles of different sizes mainly from the northwest to the southeast (Maghsoudi *et al*., 2013). We have surveyed the morphology of the two dunes as the samples to investigate about the types and behaviors of the dunes and generalize them to other fields with similar situations. Below is represented some advantages of the proposed method. The advantages of this model are standardization in calculating barchans characteristics, application of more parameters in barchans movement, use of coordinate system for barchans dune, real measurement of the dune curved horns.

4.1. Comparative analysis of barchans in other regions

One of the abilities of new and efficient methods is that make it possible to apply its rules and relations in other times and places to compare the results over time and with results in other regions. According to the FP Method, a dune is measured based upon coordinate system and the coordinates of each point relative to the origin of the Cartesian system. The parameters of dune may change over the time on the coordinates of Cartesian system so that can be compared over the time and with other dunes.

4.2. The length of barchan horns

The horns of barchans are highly important and should precisely be measured in each study about the dunes. In the study, we have calculated the horns in a curved line instead of the direct line that the direct distance from the tip of the horn to the peak of the brink were measured (Sauermann *et al.,* 2000, Burough *et al.,* 2012). It impedes to generalize the results to other studies. In FP method, the length has been measured from the tip of the horn (p1 or p2) to the peak of the brink (p4) in a curved and rounded line along the top of the horn which helps measure the length for many dunes for comparative investigation. These measurements of parameters by satellite or aerial photos may show sand characteristics and wind regime over an area (Elbelrhiti, 2005; Hesp and Hastings, 1998).

4.3. The area of forward and backward of barchans

There is not any study to measure the area of front face of dune and that of back of the dune and also the ratio of forward area to backward area. The relation of the ratio can be examined to other parameters. Significant relationship of the ratio with other parameters can be investigated to reveal the influence of processes, the dynamic behavior of dunes, and also facilitate their classification. This can be applied to explain the differences in barchans as the model outlined by Sauermann *et al*. (2000).

4.4. The curvature of horns

The parameter is one of the measures that have been calculated in FP method. It makes this possible to find out the direction of wind and the orientation along which the dune is moving. The width between the two horns in a curved line can better estimate the three dimensional windward shapes and leeward slope (Hesp and Hastings, 1998, Daniell and hughes, 2007).

4.5. Time and cost

In the studies by FP method, the field survey can easily be conducted and the required data can be gathered by survey camera or GPS equipment in a vast study area. By the method, we can record the coordinate data of just five points and extract other morphologic characteristics.

5. Conclusion

Barchan dunes in Lut Desert have particular characteristics required to be recognized for basics of geomorphological studies and some applications. By conducting FP method in study of barchans, it is possible to understand the geometric relations of barchans for a better comparison in the results of different studies. The advantage of the method is the constant geometric principle and the easy measurement and calculation of parameters. The method as mentioned is faster and needs lower cost than previous studies. It is also possible to calculate roughly all other geometric parameters of barchans for comparative analysis. With ratio of forward area to backward area of barchans available, the relationship of the ratio with other parameters can be analyzed as well as the dunes may be classified by this measure. With ratio of right length to left length available, the dunes can be classified based on the direction of prevailing winds in an area. The FP method makes it applicable to calculate the parameters of barchans through the methods used in the previous studies but it is not possible vice versa. Forward area and backward area and also maximum height can be employed to compute the significant relation between the dune parameters and their movement. By this way, the two parameters can be calculated in two successive times in order to compare changes and movements for finding the significant relations. The parameters can also be employed for classification of the dunes.

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References

Besler, H., 2008. The great sand sea in Egypt. 1st ed., Elsevier, Amsterdam, Netherlands.

Bourke, M. C., A.S. Goudie, 2009. Varieties of barchan form in the Namib Desert and on Mars. Aeolian Rsearch, 1; 45–54.

Burrough, S. L., D. S. Thomas, R. M. Bailey, L. Davies, 2012. From landform to process: Morphology and formation of lake-bed barchan dunes, Makgadikgadi, Botswana. Geomorphology, 161–162; 1–14.

Daniell, J. J., M. Hughes, 2007. The morphology of barchan-shaped sand banks from western Torres Strait, northern Australia. Sedimentary Geology, 202; 638–652.

DeMing JIANG1, C. M., 2013. Spatial heterogeneity of plant species on the windward slope of active sand dunes in a semi-arid region of China. Journal of Arid Land, 5; 80-88.

Dong, Z., D. Man, W. Luo, G. Qian, J. Ang, M. Zhao, *et al.*, 2010. Horizontal aeolian sediment flux in the Minqin area, a major source of Chinese dust storms. Geomorphology, 116; 58–66.

Dong, Z., X. Wang, G. Chen, 2000. Monitoring sand dune advance in the Taklimakan Desert. Geomorphology, 35; 219–231.

Ehsani, A. H., F. Quiel, 2008. Application of Self Organizing Map and SRTM data to characterize yardangs in the Lut desert, Iran. Remote Sensing of Environment, 112; 3284–3294.

Ehsani, A., F. Guiel, 2009. DEM-based analysis of morphometric features in humid and hyper-arid environments using artificial neural network. Desert, 14; 71-82.

Elbelrhiti, H., S. Douady, 2011. Equilibrium versus disequilibrium of barchan dunes. Geomorphology, 125; 558–568.

Elbelrhiti, H., 2012. Initiation and early development of barchan dunes: A case study of the Moroccan Atlantic Sahara desert. Geomorphology, 138; 181–188.

Elbelrhiti, H., B. Andreotti, P. Claudin, 2008. Barchan dune corridors: Field characterization and investigation of control parameters. Journal of Geophysical Research, 113; 1029-1050.

Elbelrhiti, H., P. Claudin, B. Andreotti, 2005. Field evidence for surface-wave-induced instability of sand dunes. Nature, 437; 720-723.

Fakhr Vaezi, N., A. Hajizadeh, 2013. Geodesy 1; with a look totality and the principles of Geodesy. 2nd ed., Mahvareh, Tehran, Iran.

Gay, P. S., 1999. Observations regarding the movement of barchan sand dunes in the Nazca to Tanaca area of southern Peru. Geomorphology, 27; 279–293.

Ghahroudi Tali, M., M. A. Nezammahalleh, 2012. An investigation on the origins of dust storms and their development over Iran. 1st International Forum on Airborne Dust Storms, Kermanshah.

Ghahroudi Tali, M., S. Sadough, M. Nezammahalleh, S. Nezammahalleh, 2012. Multi-criteria evaluation to select sites for ecotourism facilities a case study Miankaleh Peninsula. Anatolia – An International Journal of Tourism and Hospitality Research, 3; 373–394.

Haynes, V. C., 1989. Bagnold’s Barchan: A 57-Yr Record of Dune Movement in the Eastern Sahara and Implications for Dune Origin and Paleoclimate since Neolithic Times. Quaternery Research, 32; 153-167.

Herrmann, H. J., G. Sauermann, 2000. The shape of dunes. Physica A, 283; 24-30.

Hersen, P., K. H. Andersen, H. Elbelrhiti, B. Andreotti, P. Claudin, S. Douady, 2004. Corridors of barchan dunes: Stability and size selection. Physical Review E, 69; 1-12.

Hesp, P. A., K. Hastings, 1998. Width, height and slope relationships and aerodynamic maintenance of barchans . Geomorphology, 22; 193-204 .

Hesse, R., 2009. Do swarms of migrating barchan dunes record paleoenvironmental changes? A case study spanning the middle to late Holocene in the Pampa de Jaguay southern Peru. Geomorphology, 104; 185–190.

Howard, A. D., J. B. Morton, M. Gad- El-Hak, D.B. Pierce, 1978. Sand transport of baarchan dune equilibrium. Sedimentology, 25; 307-338.

Lam, D. K., T. K. Remmel, T. D. Drezner, 2011. Tracking Desertification in California Using Remote Sensing: A Sand Dune Encroachment Approach. Remorte Sensing, 3; 1-13.

Liu, L. Y., E. Skidmore, E. Hasi, L. Wagner, J. Tatarko, 2005. Dune sand transport as influenced by wind directions, speed and frequencies in the Ordos Plateau, China. Geomorphology, 67; 283–297.

Mashhadi, N., H. Ahmadi, M. Ekhtesasi, S. Feiznia, G. Feghhi, 2007. Analysis of sand dunes to determine wind direction and detect sand source sites (case study: Khartooran Erg, Iran). Biaban, 12; 69-75.

Mohajjel, M., 2009. Thin-skinned deformation near Shahdad, southeast Iran. Journal of Asian Earth Sciences, 36; 146–155.

Mohamed, I., G. Verstraeten, 2012. Analyzing dune dynamics at the dune-field scale based on multi-temporal analysis of Landsat-TM images. Remote Sensing of Environment, 119; 105–117.

Navarro, M., J. J. Muñoz-Pérez, J. Román-Sierra, H. Tsoar, I. Rodríguez, G. Gómez-Pina, 2011. Assessment of highly active dune mobility in the medium, short and very short term. Geomorphology, 129; 14–28.

Nezammahalleh, H., F. Farhadi, M. Tanhaemami, 2010. Conceptual design and techno-economic assessment of integrated solar combined cycle system with DSG technology. Solar Energy, 84; 1696–1705.

Oliphant, A., P. Zawar-reza, G. Azizi, A. Dehghanpour, J. Harrison, 2011. Surface energy and water vapor fluxes observed in a desert plantation in central Iran. Journal of Arid Environments, 75; 926-935.

Rashki, A., P. Eriksson, C. Rautenbach, D. Kaskaoutis, W. Grote, J. Dykstra, 2013. Assessment of chemical and mineralogical characteristics of airborne dust in the Sistan region, Iran. Chemosphere, 90; 227–236.

Sauermann, G., P. Rognon, A. Poliakov, H. J. Herrmann, 2000. The shape of the barchan dunes of Southern Morocco. Geomorphology, 36; 47–62.

Taniguchi, K., N. Endo, 2007. Deformed barchans under alternating flows: Flume experiments and comparison with barchan dunes within Proctor Crater, Mars. Geomorphology, 90; 91–100.

Taniguchi, K., N. Endo, H. Sekiguchi, 2012. The effect of periodic changes in wind direction on the deformation and morphology of isolated sand dunes based on flume experiments and field data from the Western Sahara. Geomorphology, 179; 286-299.

Todd, B. J., 2005. Morphology and composition of submarine barchan dunes on the Scotian Shelf, Canadian Atlantic margin. Geomorphology, 67; 487–500.

Walker, R., M. Talebian, S. Saiffori, R. Sloan, A. Rasheedi, N. MacBean, A. Ghassemi, 2010. Active faulting, earthquakes, and restraining bend development near Kerman city in southeastern Iran. Journal of Structural Geology, 32; 1046-1060.

Wang, Z. T., S. C. Tao, Y. W. Xie, G. H. Dong, 2007. Barchans of Minqin: Morphometry. Geomorphology, 89; 405–411.

Yang, X., L. Scuderi, T. Liu, P. Paillou, H. Li, J. Dong, B, Zhu, W. Jiang, A. Jochems, G. Weissmann, 2011. Formation of the highest sand dunes on Earth. Geomorphology, 135; 108–116.

Zheng, X., 2009. Mechanics of Wind Blown Sand Movements. Springer, Berlin Heidenberg, Germany.

ZhiBao D.ng, P. L., 2014. Aeolian transport over a developing transverse dune. Journal of Arid Land, 6; 243-254.