Journal of Social Issues & Humanities, Volume 3, Issue 3, March 2015
ISSN 2345-2633

Modeling of Sand Dunes Volume (Case Study: Barchan of Haj Ali Gholi Playa, Central Iran)

Seyed Hojjat Mousavi, Saheb Bahrami

Abstract— Barchan dunes are one of the aeolian landforms that originate from reciprocal interaction between wind flow and sand bed. These features have been formed from quicksand, and displacement is the most important of their characteristics. One of the most principle factors for prediction of barchan behaviors is dune volume which can be used to explain its movement in different spatial and temporal scales. Also, this can act as an index to determine the condition of barchan system and indicate its trends. The aim of this paper is to model the barchan dunes volume using morphometric parameters by statistical methods. Results of modeling show significant power relationships between width, length, height and area on one side and dune volume on the other side. There is a maximum significant power relationship between barchan volume and area parameter, with determination index of 0.993 and standard error of estimation of 0.169. Also, complex relationships represent several models with preference value better than simple models. There is maximum significant multiplier relationship between barchan volume, and area and height parameters, with determination index of 0.999. Therefore, we present some models with one independent variable and some models with paired independent variables. The latest models have better preference value than previous ones.

Index Terms— Barchan, Chah Jam Erg, Modeling, Regression Analysis, Volume.

1 Introduction

DIFFERENT structures of sand dunes can be observed among sedimen-tary systems which are rich and poor in terms of the amount of sediment load (Hersen, 2004: 507). Barchan dunes are one of the aeolian compressive land-forms in poor sedimentary systems in arid and semiarid environments. These dunes occur in regions that wind comes steadily from the same direction throughout the year and there is not enough sand to cover the entire surface (Bagnold, 1941; Brookfield and Ahlbrandt, 1983; Nickling, 1986; Pye and Tsoar, 1990; Bes-ler, 1992; Kocurek et al., 1992; Lancaster, 1994; Sauermann et al, 2003). Barchan dunes are crescent shaped and have two horns at their end parts. The profile of barchan horns shows the wind direction and the maximum speed in the horns toe of dune (Mahmoudi, 2000: 78). These crescent dunes have been formed from two slopes with different gradients: slip face and windward. The slip face side has maximum gradi-ent due to falling of sediment grains because of wind veloci-ty and gravity tensile force. The windward side, with fewer gradients than the slip face side, is separated from it by brink (Sauermann et al., 2003).

The most important character of barchan dunes is tem-poral and spatial displacement while preserving their cres-cent shape. Barchan movement rate is a function of its size, 3D morphology, and wind velocity. This means that for winds with same speed and intensity, there is an inverse relationship between barchan movement rate and its 3D shape. In other words; the less height and volume of bar-chan, the more its annual movement rate (Mousavi, 2009: 77). This character of barchan and their annual rush cause the destruction of natural and human structures in long-term.

The morphologic properties of barchan dunes are affected by different spatial and temporal factors. One of the most important morphologic characteristics of barchan is the vol-ume of aeolian sediment that is a function of 3D shape and morphometric parameters such as length, width, height, perimeter and area. Barchan dunes, having smaller 3D shape and less volume, have less relative stability. Thus, the volume of barchan is an important and fundamental factor in its control and estimating the stability index. The rela-tionships between barchan morphometric parameters have a close connection with their 3D morphology and mobility index. Recognition of these relationships and presentation of their models is effective in identification of barchan behavior and function. The calculation of barchan volume, with re-gard to environmental management and planning using systemic approach, is necessary to estimate the rate of input and output of material (sand grains) and energy (wind force) in barchan system. Therefore, it is possible to study and identify barchan behavior and function along its displace-ment route using this method. The method provides relative-ly accurate calculation of these items using the calculation of sand flux. Therefore, the results of this research can be useful in the systematic management of desert regions. Also, it can be fruitful in the stability plans implementation of quick-sand and the recognition of critical areas of wind erosion.

Various morphological studies have been performed on barchan dunes by geomorphologists. However, few studies have been conducted on statistical modeling and quantita-tive in-

- *Assistant Professor of Geomorphology, Department of Geography and Ecotourism, Faculty of Natural Resources and Geo Sciences, University of Kashan, Kashan, I. R. Iran. Corresponding author; Tell: +989196702813, E-mail: hmousavi15@gmail.com*
- *Graduated for M.A. of Geomorphology from University of Isfahan, & lecturer of Arvand Payam Noor University, I. R. Iran.*

vestigation of the morphologic characteristics of this landform. Quantitative and statistical evaluation of mor-phometric, geometric and 3D parameters of barchans, and finding the relationships between these parameters contrib-utes to a better recognition of this feature and its function. Furthermore, calculation of these parameters allows the es-timation of movement rate, threat and destruction value.

Modeling of barchan volume has been estimated using the equation of calculating pyramid volume (Hesse, 2008). Since the height and area of barchan are needed to calculate barchan volume as a pyramid, and the accurate calculation of area and volume of barchan is quite time consuming and difficult, the main target of this study is to present suitable models for estimating volume of barchan using various morphometric parameters. To achieve this goal, barchan volume was calculated using statistical relationships be-tween its morphometric parameters, and suitable models were presented according to the preference value of model accuracy factors. Therefore, we can easily calculate the bar-chan volume with high-accuracy, if we have at least one of these parameters (length, width, height, perimeter and area).

2 BACKGROUND

The first measurements of barchan dunes and digital modeling of their parameters were carried out in Great Sahara by Bagnold (1941) and in southern Peru by Finkel (1959). To predict motions and transformations of barchan dunes and their morphology, studies were conducted on the digital simulations by Howard and Morton (1978: 307), Wipper-mann and Gross (1986: 319), Anton and Vincent (1986: 187), Landsberg (1956: 176) and Anthonsen et al. (1996: 63). Using investigating the relationship between height and width of barchan, Hesp and Hastings (1998: 193) have introduced these relationships as factors controlling the 3D shape of barchan. Gay (1999: 273), by studying the displacement of barchan dunes in south of Peru, expressed the barchan speed has a negative relationship with its size. Sauermann et al. (2000: 47), assessed barchan dunes in southern Moroc-co, and presented a model for the barchan shape by which can define differences between barchans and their stability. Herrmann and Sauermann (2000: 24) presented models for prediction of motions and dynamic of barchan dunes in Mo-rocco. Forman and Pierson (2003: 189) surveyed sand dunes in Idaho to determine the chronology of barchans. Sauer-mann et al. (2003: 245) investigated the wind velocity and the amount of sand transport on barchan dunes; they dis-cussed the differences between saturated and non-saturated wind flows. Havholm and Running (2005: 847) have stud-ied chronology, sedimentlogy, stratigraphy and environmental characteristics of Holocene's sand dunes in southwestern Manitoba. Ting Wang et al. (2006: 405) assessed the barchan dunes in northwest China using geometric theories, and proved that the barchan height has a positive ralationship with its width; they asserted that the brink can be described through parabola shape. Daniell and Hughes (2007: 638) investigated the morphology of Australian's barchans dunes and their relationship with the type of seasonal wind regime. While studying the temporal and spatial patterns of aeolian sediment transport on the parabolic dunes, Hugenholtz et al. (2008: 13) have assessed the amount of input and output and transfer rates of sands on barchan dunes with regard to climate variables in the region. Vali et al. (2008: 411) have studied geomorphologic characteristics, and movement rate of sand dunes using satellite images in the Patagonia desert; they have concluded that existence of this sand field is a result of air general circulation and coast-line characteristics.

3 STUDY AREA

The study field is located in south of Haj Ali Gholi playa, Semnan province, central IRAN. Haj Ali Gholi playa situat-ed in southwestern of Shahroud city to south of Damghan city, is the most important playa of Semnan province. This playa is a tectonic and sedimentary hole, which is influ-enced by different geomorphic and climatic processes. The shortage of vegetation cover and moisture lead to the domi-nation of wind processes over other processes in this playa, as a result of which, we can observe several kinds of wind erosion landforms in this region. Chah Jam Erg, with an ar-ea of about 25260 hectares, is one of the most important ergs of Haj Ali Gholi playa that is located asymmetrically along northeastern - southwestern edge of the playa with a length of 10 to 12 Km (Ahmadi, 2007). The study area is located at latitudes between 35° 45' and 35° 50' North, and at longi-tudes between 54° 40' and 55° 10' East (Fig. 1).

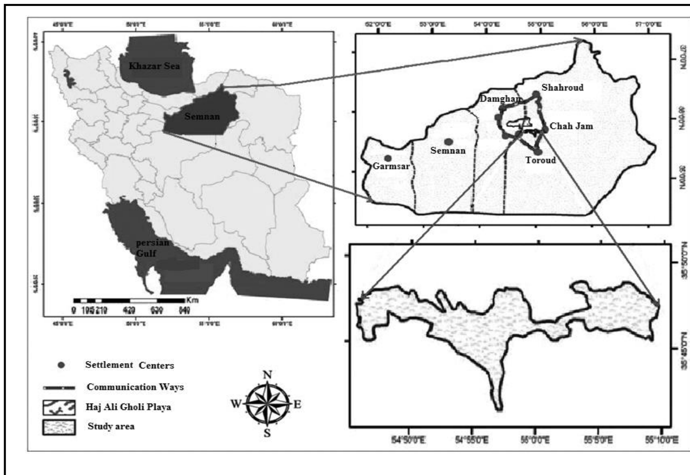

Fig. 1. Geographical position of the study area

4 METHODS AND TECHNIQUES

First, the study area was investigated by satellite images of Google Earth and 1:50000 maps. Then we sampled and measured the morphometric parameters of barchan dunes.

The common methods and units of sampling in the field studies are divided into three categories as follows (Bonham, 1989: 140): Point method: point unit (Fig. 2; A), One-dimensional method: length unit (transect) (Fig. 2, B), and Two-dimensional method: plat unit (quadrate) (Fig. 2, C).

In this study, the sampling method is based on one-dimensional method and length unit. This method provides the possibility of random sampling of barchan dunes in the

Journal of Social Issues & Humanities, Volume 3, Issue 3, March 2015
ISSN 2345-2633

entire study area. In order to cover the entire study area, some transects was considered using the GPS, and then, only barchan dunes coinciding with mentioned transects have been studied and measured, regarding figure (2, b). Sampling was performed along the 10 transects, covering almost total study area. The sample number depends on the situation of barchans on each transect. Totally, 52 barchans were measured and evaluated. In other words, 52 barchans have met the above mentioned transects (Fig. 3).

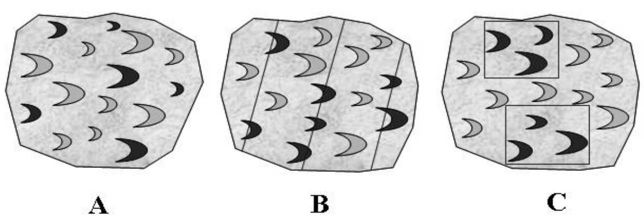

Fig. 2. Methods and units of data sampling.

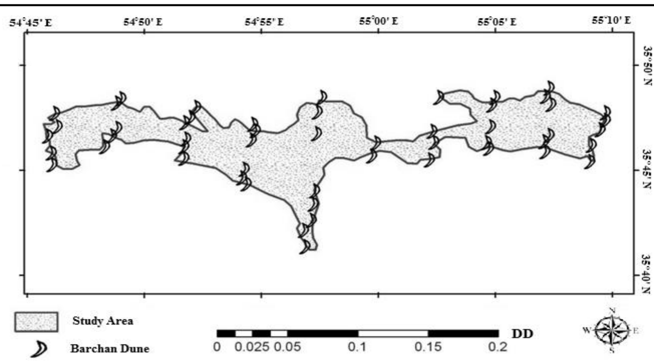

Fig. 3. The situation of measured barchan dunes in study area.

In order to study the statistical properties of barchan dunes, their morphometric characteristics were measured. Figure (4) is the basis of field measurement that shows the types of barchan morphometric parameters and their meas-urement method. The emphasis of this study is on the vol-ume (V), length (L), height (H), width (W), perimeter (P) and area (A) parameters of barchans.

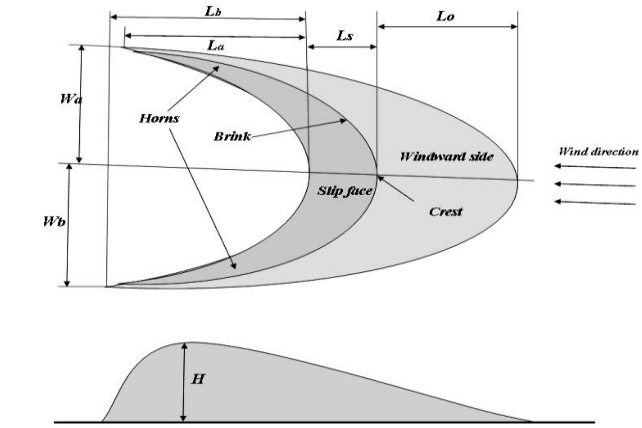

Fig. 4. Schematic explanation of the barchan morphometric parameters (height: H; right width: Wa; left width: Wb; length of right horn: La; length of left horn: Lb; length of windward side: Lo; length of slip face side: Ls).

Number equations consecutively with equation numbers in The total width (W) of a barchan is the sum of the widths Wa & Wb (equation 1). Also, the overall length (L) of a bar-chan is the sum of Lo (length of the dune windward foot to its crest), Ls (length of the slip face side), and the average of the horn lengths [(La + Lb)/ 2] as defined in equation (2).

$$W = Wa + Wb \qquad (1)$$

$$L = Lo + Ls + [(La + Lb)/ 2] \qquad (2)$$

The calculation method of barchan area and perimeter is as follows: First, a coordinate system was considered on the earth surface, for each barchan. Then, a coordinate of 24 points was determined on its perimeter using a mesh net-work. Sampled points in the field were drawn on graph pa-per of 1:200scale. Finally, the area and perimeter of each bar-chan were meas-ured by planimeter and curvimeter, respec-tively (Fig. 5).

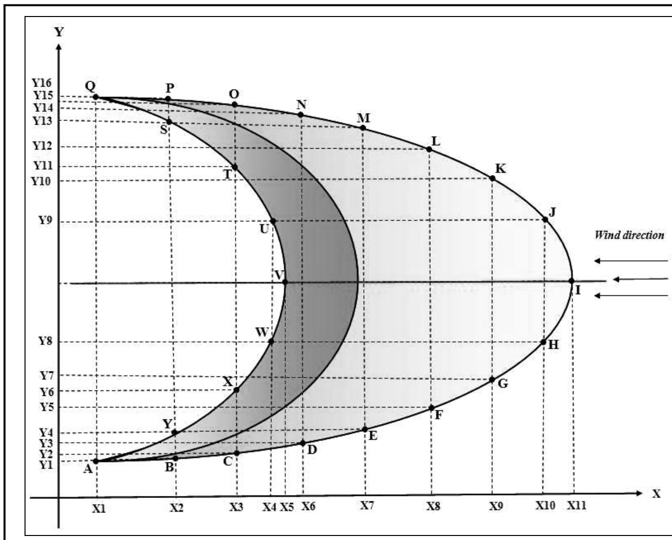

Fig. 5. Coordinates of points taken on the barchan perimeter: A(X1, Y1), B(X2, Y1), C (X3.Y2) and etc.

Barchan dunes volume (V) is a function of height and ar-ea, and was calculated as a half pyramid volume using equation (3) for all dunes (Hersen et al., 2004; Hesse, 2008).

V= 0.16666 (A × H) (3)

Where A is area and H is height of barchan dune.

Eventually, parameters of height, length and its compo-nents, width and its components, perimeter, area and vol-ume were determined for all 52 barchans. Then, a data ma-trix was pre-pared for modeling. The data sets were modeled using SPSS software and the regression analysis technique. For this purpose, first, simple and complex regression meth-ods were examined. In simple regression calculations, dif-ferent relationships such as linear, power, logarithmic, and cubic were tested for various pa-rameters. In the next step, non-linear multiple regression analysis was employed to discover the appropriate models for calculation of barchan volume. Then, the accuracy of models is determined through comparing their validity, and the most suitable was se-lected. The preference and selection indexes of relations is based on the maximum determination index, correlation index, ad-justed determination index, significance level and the min-imum standard error of estimation with an error probability of equal or less than one percent (α≤0.01).

5 Finding and Results

In the study area, we can see various barchans, most of them having same and similar shapes (Fig. 6). Generally, the bar-chans of this region have a height of 2.1 to 17.9 meters, a length of 19.5 to 307.85 meters and a width of 6.3 to 165.6 me-ters. The other properties of studied barchans are given in Ta-ble (1).

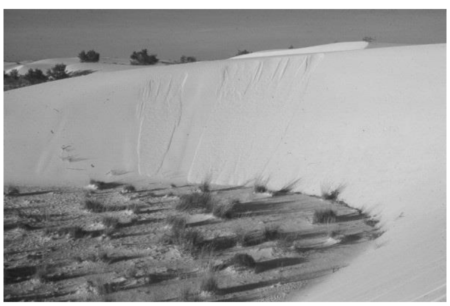

Fig. 6. A picture of barchan dune in study area.

TABLE 1
DESCRIPTIVE STATISTIC OF MORPHOMETRIC PARAMETERS OF STUDIED BARCHAN

Parameter*	Minimum	Maximum	Average	Standard Deviation	Skewness
H	1.2	17.9	5.802	3.768	1.244
Wa	3.1	89.1	27.311	17.658	1.195
Wb	3.2	94.6	32.796	21.672	1.051
W	6.3	165.6	60.107	37.93	0.966
La	4.2	80.5	29.498	20.191	0.103
Lb	1.5	89.3	35.573	22.673	0.728
Lo	9.1	223.6	52.467	42.761	1.727
Ls	1.5	39.4	9.667	7.361	1.647
L	19.5	307.85	94.67	65.141	1.134
V	7.94	64379.3	7.8524E3	12808.6	2.539
P	81.2	30824.51	5.0813E3	5907.21	2.121
A	75.15	1038.15	3.2725E3	206.571	1.243

*- Height, length, width and perimeter are given in meter and area and volume are given in square meter (m2) and cubic meter (m3), respec-tively

The obtained results from the study of simple relation-ships between volume and height, width, length, perimeter and area of barchan which has been analyzed using simple regression analysis method, presented in tables (2) and (3) and figure (7). In this study, power equations gave the best results. Therefore, in this part, we have only mentioned power relationships.

TABLE 2
THE SIMPLE RELATIONSHIPS BETWEEN VOLUME AND OTHER MORPHOMETRIC PARAMETERS OF STUDIED BARCHANS

Parameter*	Type of relation	R	R2**	Adjusted R2	Std. error of estimate	Sig.
V & W	Power	0.962	0.924	0.923	0.538	0.000
V & L	Power	0.974	0.949	0.948	0.445	0.000
V & H	Power	0.983	0.966	0.965	0.363	0.000
V & A	Power	0.996	0.993	0.992	0.169	0.000
V & P	Power	0.976	0.953	0.952	0.425	0.000

*- W: width (m), L: length (m), H: height (m), P: perimeter (m) A: area (m2), V: volume (m3)
**- α ≤ 0.01

The results of table 2 indicate a maximum significant power relationship between volume and area, with a deter-mination index of 0.993 and a standard error of estimation of 0.169. The other presented relationships in table 2 are also valid, and have acceptable determination index, standard error and sig-nificant level.

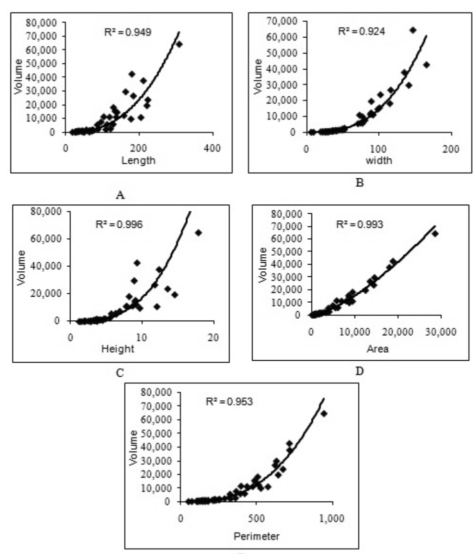

Fig. 7. The simple Relationships between volume and other morpho-metric parameters of studied barchans; A: Relationship between volume and length, B: Relationship between volume and width, C: Relationship between volume and height, D: Relationship between volume and area, E: Relationship between volume and perimeter.

With regard to the power equations structure that is the same as equation (4), two parameters (coefficient and power of equation) are necessary to present this model.

Y= b0 X b1 (4)

Where b0 is coefficient and b1 is power of equation.

The discovered coefficients and relationships between the volume and other parameters of studied barchans have been reported in table (3). Also, the significance level test of equations coefficients has been presented.

TABLE 3

COEFFICIENTS OF EXISTING RELATIONSHIPS BETWEEN VOL-UME AND OTHER MORPHOMETRIC PARAMETERS OF STUDIED BARCHANS

Parameter	Equation indexes	value	Standard Deviation	T Value	Sig.	Equation*
V & W	Coefficient	0.042	0.019	2.280	0.027	V= 0.042 W 2.748
	power	2.748	0.111	24.743	0.000	
V & L	Coefficient	0.015	0.006	2.550	0.014	V= 0.015 L 2.72
	power	2.72	0.090	30.359	0.000	
V & H	Coefficient	15.177	2.090	7.263	0.000	V= 15.177 H 3.067
	power	3.067	0.082	37.35	0.000	
V & A	Coefficient	0.025	0.003	7.164	0.000	V= 0.025 A 1.449
	power	1.449	0.018	81.626	0.000	
V & P	Coefficient	0.000243	0.000122	1.992	0.051	V= 0.000243 P 2.855
	power	2.855	0.089	31.854	0.000	

*- W: width (m), L: length (m), H: height (m), P: perimeter (m) A: area (m2), V: volume (m3)

The obtained results from multiple statistical modeling between volume and other parameters have been described in table (4). The general form of their equations can be seen in equation (5).

Y= b0 X1 X2 (5)

Where b0 is coefficient, X1 and X2 are independent varia-bles and Y is dependent variable.

The results of table (4) indicate a maximum significant relationship between volume on one side and area and height on the other side, with a determination index of 0.999. The other presented relationships in table (4) are also valid, and have acceptable determination index

TABLE 4

THE OBTAINED RESULTS OF MULTIPLE MODELING OF BAR-CHANS VOLUME WITH SPECIAL RELATIONSHIPS

Parameter*	R2**	coefficient (b0)	Equation
V with W & L	0.876	1.299	V= b0 (W × L)
	0.887	0.01	V= b0 (W2 × L)
	0.995	0.006	V= b0 (W × L2)
V with W & H	0.871	21.897	V= b0 (W × H)
	0.912	1.79	V= b0 (W2 × H)
	0.994	1.772	V= b0 (W × H2)
V with W & A	0.887	0.016	V= b0 (W × A)
	0.795	0.01 × 10 -9	V= b0 (W2 × A)
	0.839	7.55 × 10 -7	V= b0 (W × A2)
V with A & L	0.995	0.01	V= b0 (A × L)
	0.833	3.99 × 10 -7	V= b0 (A2 × L)
	0.915	3.66 × 10 - 5	V= b0 (A × L2)
V with H & A	0.999	0.77	V= b0 (H × A)
	0.926	0.011	V= b0 (H2 × A)
	0.843	6.9 × 10 -6	V= b0 (H × A2)
V with L & H	0.917	12.312	V= b0 (L × H)
	0.945	0.052	V= b0 (L2 × H)
	0.935	0.875	V= b0 (L × H2)

*- W: width (m), L: length (m), H: height (m), A: area (m2), V: vol-ume (m3). **- α ≤ 0.01

The comparison of derived results from simple and mul-tiple regression analysis (tables 2 to 4) showed that the most appropriate relationships for modeling barchan volume are as follows (equation 6 to 13). To achieve this, first, the most suitable models were determined based on the maximum R square, and then, the best models were selected according to preference value.

V= 15.177 H 3.067 (6)

V= 0.025 A 1.449 (7)

V= 0.77 (H × A) (8)

V= 0.01 (A × L) (9)

V= 1.772 (W × H2) (10)

V= 0.052(L2 × H) (11)

V= 0.006 (W × L2) (12)

V= 0.016 (W × A) (13)

Where height (H), length (L), width (W) and perimeter (P) are given in meter and area (A) and volume (V) are given in square meter (m2) and cubic meter (m3), respectively.

Comparing the results of above mentioned relations, equations (7), (8) and (11) had the maximum determination index and the minimum standard error of estimation were selected for the calculation of barchan volume using the sta-tistical models. Using these models we can easily calculate the barchan volume through length, width, height, perimeter and area parameters, and there is no need for complex mathematical equations. The obtained results were com-pared with the results of similar studies and the validity of our equations was confirmed (table 5).

TABLE 5

THE OBTAINED RESULTS OF MULTIPLE MODELING OF BAR-CHANS VOLUME WITH SPECIAL RELATIONSHIPS

Researcher	Study area	Equation*
Hess (2008: 3)**	southern Peru	V= 0.16666 (W2 × H)
Lima et al. (2002:489)***	Morocco	V= 0.05 (W3)
This study	Chah Jam Erg (Iran)	V= 0.025 A 1.449
This study	Chah Jam Erg (Iran)	V= 0.77 (H × A)
This study	Chah Jam erg (Iran)	V= 0.006 (W × L2)

*- W: width (m), L: length (m), H: height (m), A: area (m2), V: volume (m3)

**- Hess (2008: 3) considered half pyramid volume as base to present this equation (V= 0.16666 (W2 × H)), with this difference that he assumed barchan area as a square with same width and length, and calculated the barchans area through W2.

***- Lima et al. (2002: 489) have reported the equation (V= 0.05 (W3)) valid to calculate barchan volume. In this equa-tion, barchan is assumed as a cube that having the equal dimensions (height, width and height). Also, barchan vol-ume is calculated through W3 and it was multiplied by a coefficient of 0.05.

6 Discussion and Conclusion

The rush of quicksand in the form of barchan dunes to infra-structures is one of the most important environmental prob-lems of study area. The motion of sand dunes, especially barchans, leads to the destruction of agricultural lands, ur-ban and rural centers and communication ways. The conse-quences of quick-sand movement can be seen as follows: the ruining of residential regions, rural migration and large economic losses. In order to identify and systematically solve the environmental problems, limiting factors should be considered. Analyzing these factors will help scientific and research centers which try to achieve re-gional sustaina-ble development. However, precise recognition and assess-ment of barchan dunes and scientific analysis of their prop-erties can be useful in environmental management and planning. Since the behavior of landforms such as barchan is a function of their form, morphometric parameters of bar-chan dunes can act as determining factors for recognition of its behaviors and functions. The barchan volume is the best indicator of its 3D morphology. Therefore, modeling the bar-chan volume can contribute to the analysis of barchan be-havior. In this study, several models have been designed and presented based on the giv-en results. These models pro-vide the exact and rapid calculation of barchan volume us-ing its morphometric and geometric pa-rameters.

Interaction among climatic processes, obstacles of earth surface and aeolian sediments are the main causes of crea-tion of barchan dunes in the study area. Barchan dunes have been formed from quicksand, and displacement and lateral movements is the most important of their characteristics. These features migrate along prevailing wind, while main-tain their crescent shape and 3D morphology.

In this paper we have used simple and multiple regres-sions analysis methods to model the barchan volume. As a result, we have presented several models that can be used to calculate the volume of barchan dunes. The results of this study allow the exact and rapid calculation of barchan vol-ume using its morphometric parameters. According to re-sults of the research, comparative analysis of simple and complex models shows the importance of modeling ap-proaches and presenting various models.

Acknowledgment

The authors wish to thank Dr A.A. Vali, and Dr M. Mayeri. This work was supported in part by their knowledge and science.

References

[1] Ahmadi H., 2004. Applied Geomorphology (Desert – Windy erosion). 2nd Volume, 3rd edition, Tehran, Tehran University Press, pp. 328.

[2] Anthonsen K.L., Clemmensen L.B., Jensen J.H., 1996. Evolution of a dune from crescent to parabolic form in response to short-term climatic changes — Rabjerg- Mile, Skagen-Odde, Denmark. Journal of Geomorphology, 17: pp. 63–77.

[3] Anton D., Vincent P., 1986. Parabolic dunes of the Jafurah Desert, Eastern Province, Saudi Arabia. Journal of Arid Environments, 11: pp. 187–198.

[4] Bagnold R.A., 1941. The Physics of Blown Sand and Desert Dunes. Methuen, London.

[5] Brook F.J., 1999. Stratigraphy and landsnail fauna's of Late Holocene coastal dunes, Tokelau Beach, northern New Zealand. Journal of the Royal Society of New Zealand, 29: pp. 337–359.

[6] Bonham C.D., 1989. Measurement for Terrestrial Vegetation. John wiley & Sons, Inc.

[7] Daniell J., Hughes M., 2007. The morphology of barchan-shaped sand banks from western Torres Strait, northern Australia. Journal of Sedimentary Geology, 202: pp. 638-652.

[8] Finkel H.J., 1959. The barchans of southern Peru. Journal of Geology, 67: pp. 614–647.

[9] Forman S.L., Pierson J., 2003. Formation of linear and parabolic dunes on the eastern Snake River Plain, Idaho in the nineteenth century. Journal of Geomorphology, 56: pp. 189–200.

[10] Gay S.P., 1999. Observations regarding the movement of barchan sand dunes in the Nazca to Tanaca area of southern Peru. Journal of Geomorphology, 27: pp. 279–293.

[11] Hastenrath S., 1967. The barchans of the Arequipa Region, Southern Peru. Zeitschrift fur Geomorphology, 11: pp. 300–331.

[12] Havholm K.G., Running G.L., 2005. Stratigraphy, sediment logy, and environmental significance of late mid-Holocene dunes, Lauder Sand Hills, glacial lake Hind Basin, southwestern Manitoba. Canadian Journal of Earth Sciences, 42: pp. 847–863.

[13] Herrmann H.J., Sauerman, G., 2000. The shape of dunes. Physical A, pp. 283.

[14] Hersen, P., 2004. On the crescentic shape of barchan dunes. The European Physical Journal B, 37: pp. 507–514.

[15] Hesp P., Hastings K., 1998. Width, height and slope relationships and aerodynamic maintenance of barchans. Journal of Geomorphology, 22: pp. 193–204.

[16] Hesse R., 2008. Do swarms of migrating barchan dunes record pale environmental changes? — A case study spanning the middle to late Holocene in the Pampa de Jaguay, southern Peru. Journal of Geomorphology, 47: pp. 1 – 6.

[17] Howard A. D., Morton J. B., Gad-El-H, M., Pierce D.B., 1978. Sand transport model of barchan dune equilibrium. Journal of Sedimentology, 25: pp. 307–338.

[18] Hugenholtz C.H., et al., 2008. Spatial and temporal patterns of aeolian sediment transport on an inland parabolic dune, Bigstick Sand Hills, Saskatchewan, Canada. Journal of Geomorphology, 77: pp. 1- 13.

[19] Kocurek G., Townsley M., Yeh, E., Havholm K. & Sweet M. L., 1992. Dune and Dune-Field Development on Pardre Island, Texas, with Implocations for Interdune Deposition and Water-Table-Controlled Accumulation. Journal of Sediment. Petrol, 62: pp. 622–635.

[20] Lancaster N., 1994. Dune morphology and dynamics. In: Abra- hams, Parsons _Eds., Geomorphology of Desert Environments, Chapman & Hall, London, pp. 474–505.

[21] Landsberg S.Y., 1956. The orientation of dunes in Britain and Denmark in relation to wind. Geographical Journal, 122: pp. 176–189.

[22] Lima A.R., Sauermann G., Herrmann H.J., Kroy K., 2002. Modeling a dune field. Physica A, 310: pp. 487 – 500.

[23] - Mahmoudi F.A., 2000. Dynamic geomorphology, 2nd edition. Tehran. Payam Noor University publication, pp. 65-89.

[24] Mousavi S.H., 2009. The assessment of effectiveness Barchan morphometry on stabilities (Case study: Erg Chah Jam). M.A. Thesis, University of Isfahan, Isfahan, Iran, pp 1-115.

[25] Marín L., Forman S. L., Valdez A. & Bunch F., 2005. Twentieth century dune migration at the Great Sand Dunes National Park and Preserve, Colorado, relation to drought variability. Journal of Geomorphology, 70: pp. 163–183.

[26] Nickling W.G., 1986. Aeolian Geomorphology. Allen and Unwin, London, pp 87.

[27] Pye K. & Tsoar H., 1990. Aeolian Sand and Sand Dunes. Unwin Hyman, London, pp 43.

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

[29] Sauermann G., Andrade J.S., Maia L.P., Costa U.M.S., Araujo A.D., Herrmann H.J., 2003. Wind velocity and sand transport on a barchan dune. Journal of Geomorphology, 54, pp. 245 – 255.

[30] Ting Wang Z., Chen Tao S., Wen Xie Y., Hui Dong G., 2007. Barchans of Minqin: Morphometry. Journal of Geomorphology, 89, pp. 405-411.

[31] Valle H.F.del., Rostagon F.R.C.M., Coronato F.R., Bouza P.J., Blanceo P.D., 2008. Sand dune activity in north-eastern Patagonia. Journal of arid Environment, 72: pp. 411-422.

[32] Wippermann F.K., Gross G., 1986. The wind-induced shaping and migration of an isolated dune: A numerical experiment. Boundary-Layer Meteoric, 36