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Morphometric characteristics of Yardangs in the Lut Desert, Iran

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Abstract

Yardangs are one of the most amazing geomorphic features of Lut desert, Iran developed in alluvial deposits of Pleistocene. They appear as the streamlined hills that are separated by U-shaped troughs with a flat-topped. The study of yardang's morphometric parameters is important to define their morphological indices. In This study, we describe the morphology of yardangs in the Lut playa, analyze the wind factor, and discuss their development processes. Up to 132 yardangs have been identified and measured by linear sampling method along 9 transects (with 10 km length) located on digital elevation model (10×10 m) in the Global Mapper software. The obtained results of simple regression showed the central and the northern areas have the maximum correlation respectively between the width and length of yardangs. The length-to-width ratio is close to 3.5:1. The yardangs size and height in the center and north of the region are more than the southern side. This represents further evolution of yardangs where exist in the south and side of region. Wind and water erosion plays a particularly important role in this process.

Keywords: Lut Desert; Iran; Wind deflation; Yardangs; Geomorphometry

1. Introduction

Yardangs are streamlined hill shape carved from bedrock or any consolidated or semi consolidated material by the dual action of wind abrasion, dust and sand, and deflation (Ami, 2016; Webster, 2002). They are found in areas with strong winds, dry climate and erosion-prone lands (Ahmadi, 2006). Yardangs exist in several deserts of world, such as Lut Desert in Iran, the Egyptian deserts, the Libyan Desert, Taklimakan Desert in China, Borkou region of Chad, Namib Desert of Namibia, the coastal desert of Peru and near Rogers Lake in California, U.S.A (Dong and Dong, 205; Dong *et al*., 2012).

In Iran, yardangs cover a wide area of central Lut Desert (4% four percent of the desert) (Krinsley, 1970). They have been developed in a basin filled deposits of Pleistocene (gypsiferous sands, silty clays). They exist in parallel ridges and corridors form that match with 120-day winds of Sistan (333 degrees) (Krinsley, 1970). The area of yardangs is about 150 km long and 70 km wide and they run from northwest to the southeast (Mashhadi, 2003, Mousavi, 2015).

Yardang can be resembled a hull of an inverted boat, facing the wind is a steep that typically highest and widest at the blunt end and it gets lower and narrower toward the lee end (li *et al*., 2016; Ward and Greeley, 1984). Lut yardangs are up to 80 meters high and they vary from a few to hundreds of kilometers in length; the corridors between them can be more than 100 meters in width (McCauley *et al*., 1977). There is about 10-15 cm thick of gypsiferous clay blankets the yardangs, which inhibits further growth of the water erosion rills on the steep margins of the features. The stratum was the survivor of the wet period in the past which shows lack of water erosion on Yardangs surfaces at current condition (Mahmoudi, 1971). Yardangs shape and dimensions depend on the several factors namely, type of bedrock, the roughness of land surface, intensity and frequency of wind (McCauley *et al*. 1977; Gutie´rrez-Elorza, *et al*., 2002, Goudie, 2007). Lut yardangs generally based on dimensions and erosion factors are divided into two types:

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small yardang have been formed under the influence of wind erosion (with one m to a few meters size) and Large yardangs which have been formed from water-wind erosion (up to tens of meters) (Ahmadi, 2006). First, Hedin (1903) applied the term "Yardang" for the features as a Turkish word in his research on the Taklimakan desert in the east of China.

Recently, the advancements in science and technology has made yardangs studies easier through aerial photographs and satellite (Mainguet, 1968, 1972; Halimov and Fezer, 1989, Ehsani and Quiel, 2008; Zimbelman and Griffin, 2010; Sebe *et al*., 2011).

Some researchers completed their analyses by field observations and laboratory experiments (Guo *et al*., 2012; Whitney, 1978, 1983; Ward and Greeley, 1984). McCauley *et al* (1977) have provided a global map of large yardangs over the world.

Laity (2009) has stated that wind is the most important factor in sculpting yardangs and he considered other agents such as weathering processes or water erosion less important.

Study of yardangs morphometry have been conducted in several studies (Ward and Greeley, 1984; Halimov and Fazer, 1989; Goudie *et al*. 1999). The results also show a considerable range in yardangs scales, so they have been classified by size to: micro yardangs (some centimeter scale ridges), meso-yardangs (some meters in height and length) and mega-yardangs that may be tens of meters high and several kilometers long (McCauley *et al*. 1977,; Grolier *et al*., 1980; Cooke *et al*., 1993; Carling, 2013). Dong *et al* (2012) describe the morphology of yardangs in the Kumtagh Desert of China and they show that the formation of yardangs can be divided into four stages: an embryonic stage, adolescence, maturation, and recession.

Gabriel (1938) has reported that mega-Yardangs are located on Pleistocene clays and silts rock type in The Lut Desert of southern Iran.

The yardangs in Lut desert were situated in dry areas where vegetation cover is minimal, and where sand abrasion happen very much. The yardangs may not remain if the climate changes to more humid conditions (McCauley *et al.*, 1977).

Some important features of the Lut yardangs (rock type, water resources, soil moisture, physiography, genesis and morphometry) were obtained in some research in which using remote sensing images and aerial photographs was applied (Mashhadi *et al.*, 2003; Alavipanah, 2003 and 2007, Ehsani and Quiel , 2008). Ehsani (2010) in the same study of Lut yardangs has shown some morphological characteristics of yardangs and classified them into several subgroups. The results of researches have been showed that yardangs are probably one of the least understood landforms of the Earth’s surface.

The recognition of yardang’s morphometric parameters is important in the definition of their morphological indices (Goudie *et al*., 2016), and relationships between them can be considered as modeling infrastructures of form, natural and phenomenal indices. So, the purposes of this study are the assessment of relationships and representation of models between morphometric parameters and grouping of Lut yardangs using statistical methods.

2. Materials and Methods

2.1. Study area

The study area is located in the western part of the Lut playa adjusted to Kerman mountains. Lut playa (Lut desert) is a large salt desert in southeastern Iran. It has been known as the hottest place on earth at nearly 70.7 degrees C (159-160 degrees F) (Mildrexler *et al*., 2006), and is one of the world's driest places. Area of the desert is about 51,800 square kilometers (20,000 sq mi). The eastern part of Lut desert is a low plateau covered with salt flats. This area consists of sand dunes which some of them are known as the highest dunes in the world reaching a height of 300 m (Ehsani, 2009; Ehsani and Quiel, 2009). The western part of playa is covered with unique yardangs that are called Kelout in local language. The yardangs, with 6481.6km^2 is located between 29° 30' N and 30° 49' N, and 57° 47' E and 59° 53' E (Fig. 1). A climatological factor which is governing on the study area is the prevailing wind known as “wind of 120 days of Sistan” blowing from NNW–SSE corresponds exactly to the direction of elongated yardangs (Masoodian, 2014). It starts in April with average velocity of 9.35 m/s. The mean annual wind speed is 6m/s. The elevation ranges from100 m in the north and east to 404 m a.s.l. in the central and southeast of the Lut playa. The slopes range from 0 to 19° and geologically, yardangs are formed in Pliocene Lut strata, which is composed of fine-grained horizontally, bed red to light-brown and limy gypsiferous sands with an estimated thickness of 135 to 200 m. Salt, gypsum, and silty clay encrust the unit (Krinsley, 1970).

Methodology

At first, the studied area was recognized by satellite images and digital elevation model (Fig. 1). Then, yardang morphometric parameters are sampled and measured. The samplings were done random-systematic along 9 transects with 10 km length that are drawn upon digital elevation model (with sell size 10 × 10 meters) in Global Mapper software.

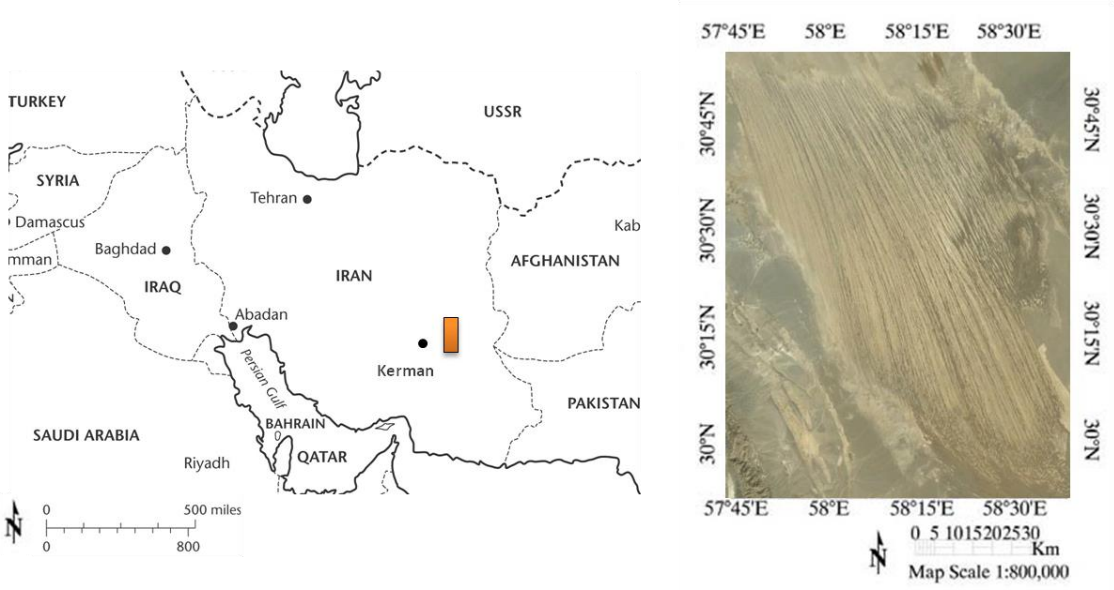


Fig. 1. Location map of the study area

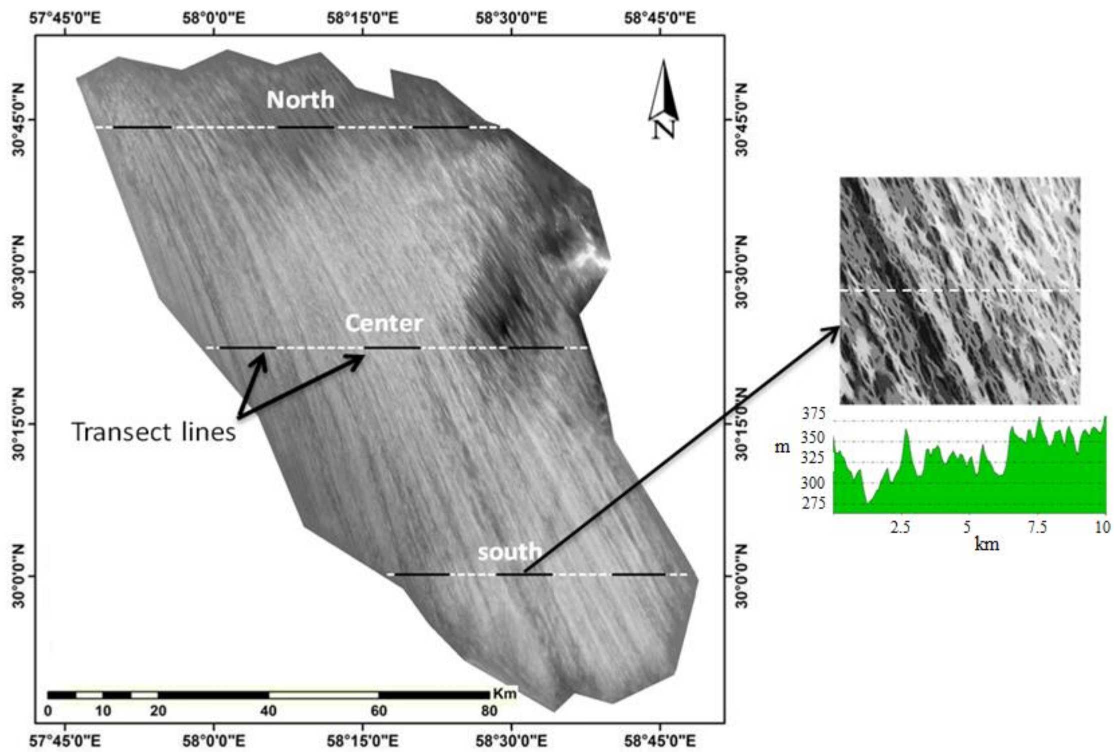


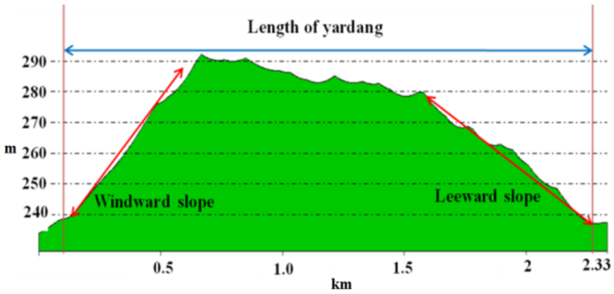
Fig. 2. Transects location and the sampled Yardangs in the study area

132 yardangs are assessed that 42, 40 and 50 numbers belong northern transects, central transects and southern transects respectively (Fig. 2). To evaluate and modeling the yardangs, their morphometric parameters were measured via drawing length profile according to ridge and cross-section matching to summit of yardangs upon DEM by Global Mapper 13

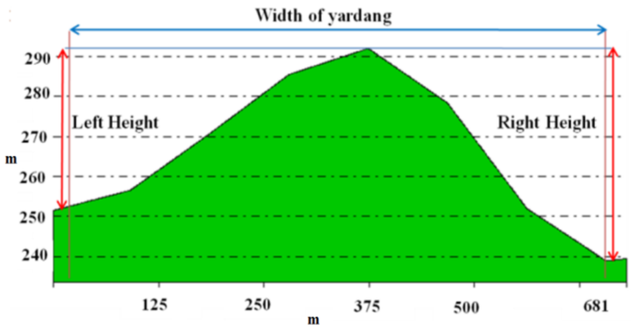
software (Mousavi, 2015). So that, length, windward slope, leeward slope parameters along length profile and right height, left height and width parameters along cross-section were measured (Fig. 3). Mean height is calculated through average of right height (Ha) and left height (Hb)

Eq. (1): (Ha + Hb)/2 (1)

The morphometric characteristics data of yardangs in three areas were analyzed according to a completely randomized design and in case of a significant F-test, means were compared by LSD test.



a: Length profile



b: Cross section

Fig. 3. Schematic explain of measurement technique for yardang morphometric parameters

3. Result and Discussion

Up to 132 yardangs have been identified in the study area including 40, 42 and 50 numbers in the north, center and south respectively (Table1). The main direction of the yardangs coincides with direction of 120-day winds of Sistan (Fig. 4). The frequency distribution of yardangs morphometric parameters in different areas is shown in Figs 5, 6, 7 which indicates that, generally all of them have numerous sizes.

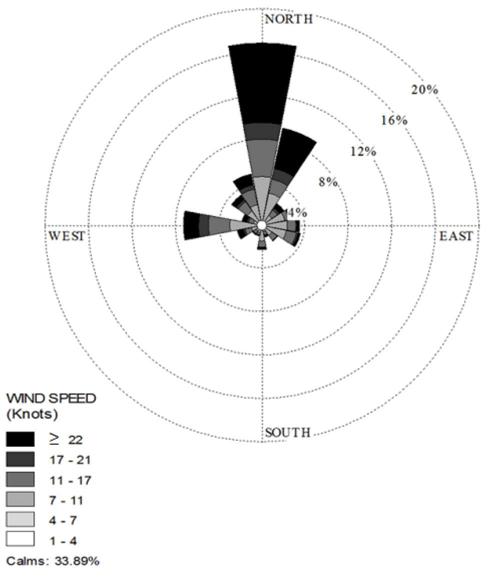


Fig. 4. The annually wind rose of Shahdad synoptic station

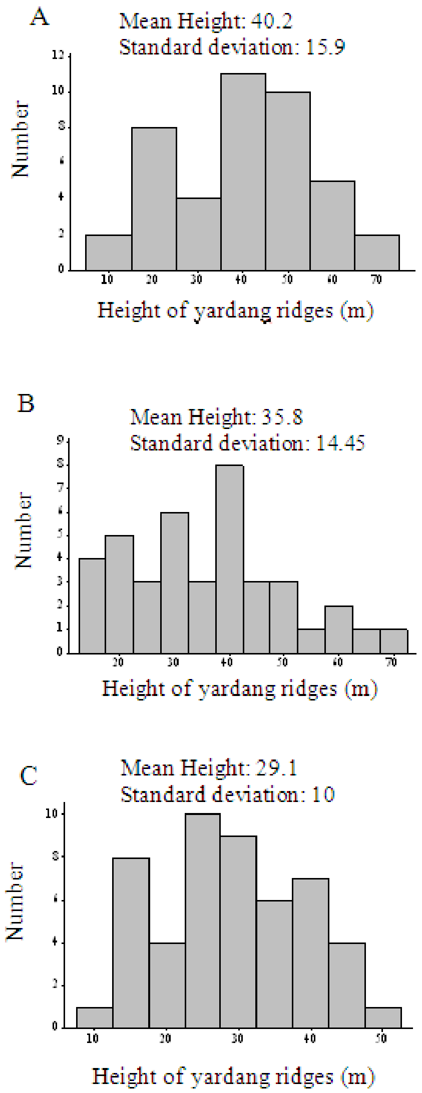


Fig. 5. Frequency distribution for the Height of Yardangs. (A) northern area. (B) central area. (C) southern area

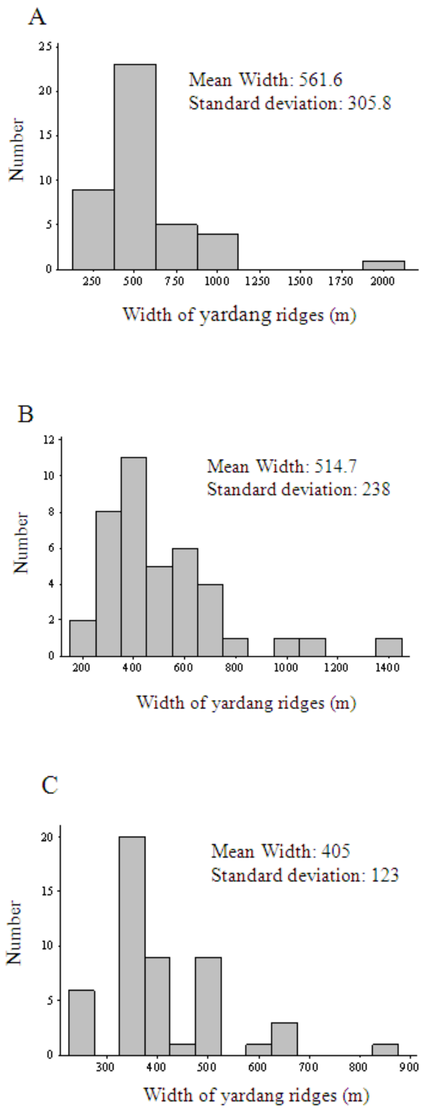


Fig. 6. Frequency distribution for the Width of Yardangs. (A) northern area. (B) central area. (C) southern area

The maximum length, width and height of the yardangs are 6663, 2000 and 71 m, respectively. They are mainly having mean heights between 29.1 to 40.2 meters, lengths between 1077 to 2110 meters and widths between 405 to 561.6 meters (Figs. 5, 6, 7). The average length/width ratio is 3.5:1 (Fig. 5). These relations are in agreement with the values ratio obtained in yardang forms measured by Grolier *et al.*, (1980) and differ from the 10:1 ratio in Borkou in the Sahara Desert (Cooke *et al.*, 1993).

Table1. Comparing the mean of Yardangs morphometric parameters

Area	Number	Lenght	Width	Height	Ratio1/w	Slope	
						Windward	Leeward
North	42	2110^{a*}	562^{a}	40.2^{a}	3.8^{a}	17.9 ^{a}	7^{a}
Center	40	2158^{a}	515^{a}	35.8^{a}	4.2^{a}	15.7 ^{a}	7.4^{ab}
South	50	1077^{b}	405^{b}	29.1^{b}	2.7^{b}	15.7 ^{a}	8.4^{b}
Total	132	1733	488	34.7	3.5	16.4	7.7

* Similar letters indicate no significant difference between treatments at 5% level

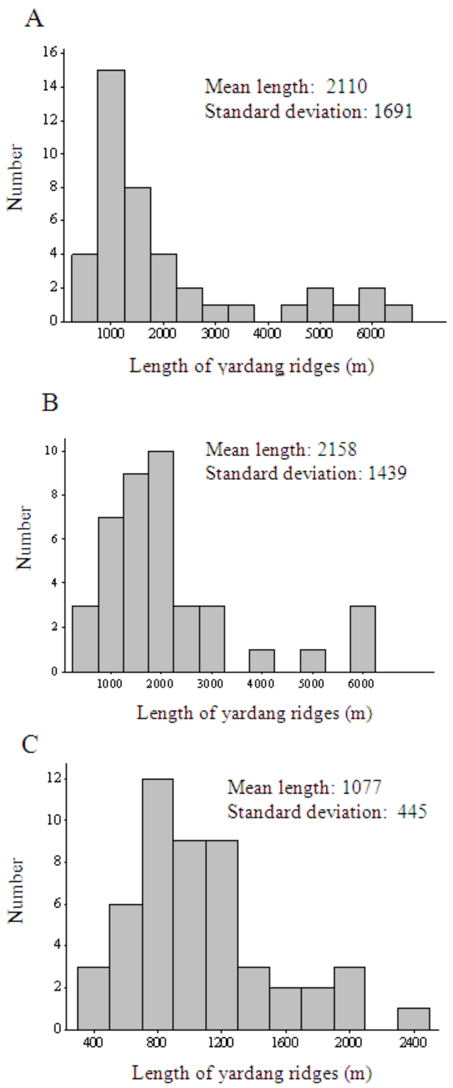


Fig. 7. Frequency distribution of Yardangs length. (A) northern area. (B) central area. (C) southern area

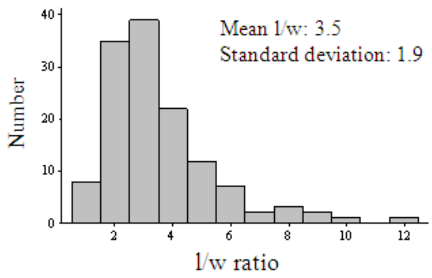


Fig. 8. Frequency distribution of yardangs width/length ratio

The mean angles of windward and leeward slopes of the yardangs are 16.4 and 7.7 percent respectively. So, the windward slope is steeper than the leeward slope and statistical comparisons show significant difference between them at 5% level, whereas the incline of the leeward slope shows a progressive decline towards the downwind Sequence (Fig 9). The obtained results from simple regression show the significant linear correlation of windward and leeward slopes with determination coefficient 0.31 (Fig 10). Also the results of McCauley *et al*, 1977, Gutie´rrez-Elorza, *et al*., 2002, Mashhadi *et al*., 2003 showed a significant linear correlation between windward and leeward slopes.

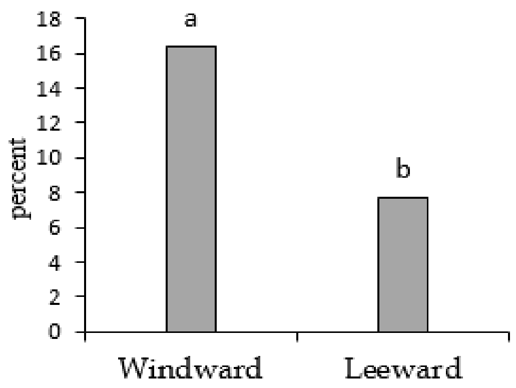


Fig. 9. The change of slope mean

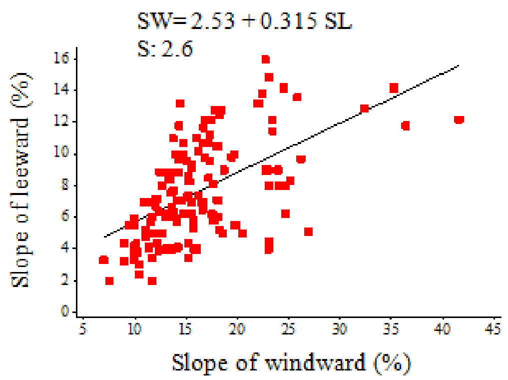


Fig. 10. Relationship of Windward slope: Leeward slope for all yardangs
* SW = Slope of windward, SL= Slope of leeward

Table 2. Length: width regression analysis for yardangs

Area	regression equation	Variance	*Determination coefficient	P value
North	*W = 357 + 0.097 L	261.4	28.7	0.0
South	W = 305 + 0.093 L	117	11.3	0.01
Center	W= 263 + 0.12 L	170.8	49.8	0.0

* W=Width, L = Length
Determination coefficient =R^2

Table 1 shows variance analysis and comparison of means related to the number of yardangs in each region (Fisher test). As you can see in the table 1, the yardangs morphometric parameters are increased in center and north of region in comparison with the south. The length, width, height and the l/w ratio of the south show a significant difference in P<0.05. These results confirm the studies of Mashhadi (2002) and Ahmadi (2006). The Windward slope is not significant in three areas. The leeward slope has a significant difference between south and north (P<0.05) (Table 1).

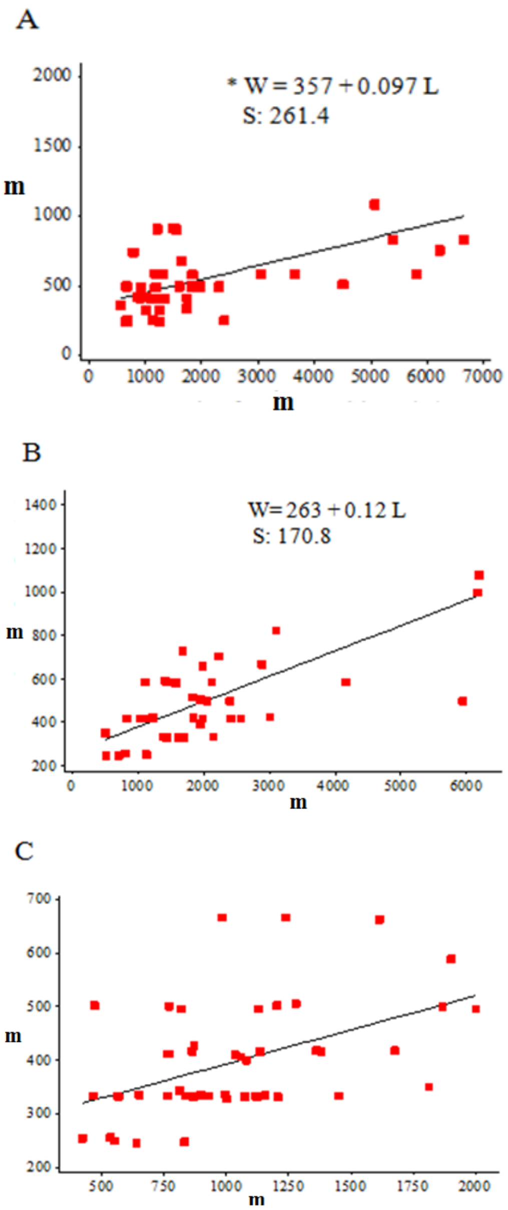


Fig. 11. Length: width relationship for yardangs
x axis: width of yardang, y axis: length of yardang
(A) Northern area. (B) Central area (C) Southern area
* S = Variance, W=Width, L = Length

The results show that the width of yardangs has a significant relationship of about 95% with length in three regions studied. The center and the north area have the maximum determination coefficient (0.50 and 0.29) respectively and there is the lowest correlation between width and length with coefficients of 0.11 in the south area (Table 2). The results of stepwise regression indicates that 50%, 29% and 11% of yardangs width changes is explained by length in the center, north and south respectively. But these variables are not the most efficient factors to estimate the Yyardangs width or length (Fig.11, Table 2).

4. Discussion and Conclusion

The observations showed that the yardangs direction is the north and northwest to south and southeast but a little diversion were found in the order of some of them. The obtained results indicate that the yardangs size and height in the center and north of region are more than the south. Yardangs developed to thin and slurred walls in the margin. It proves that the yardangs were in an unstable environment especially in terms of climate. Further evolution of yardangs where exist in the side of region is due to the checkerboard distribution of yardangs that shows the accumulation of wind while moving through the yardangs. The intensity of wind abrasion in grooves floor is 3 to 4 times more than the mounds. We can explain it by The Ventori wind speed measurement device that shows the wind speed is higher in a corridor than an open area (Mainguet, 1983) and also according to the Bernoli rule the wind speed is much more in the Yardangs area toward the near hills in Lut dessert (Moghimi, 2005). It can be said that wind erosion plays a particularly important role in this result. The dominant long-term unidirectional winds, coarse particles are carried by high speed wind and some other factors such as lithology, evolution of water erosion in the past, lack of vegetation and age of formation could be effective in the Lut yardangs development as well (Mousavi, 2015).

The highest point and the maximum slope in initial of windward face could be due to deviation of wind by broad width of yardang. Also, the elongation, narrow part, minimum of elevation and slope in the leeward end of yardang are justified using wind convergence, reinforcement of its shear velocity and predominance of wind upon ridge (Fig. 12).

Fig. 12. Lut Yardang developed in the Pleistocene gypsiferous deposits and silty clays. The arrow indicates wind direction

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