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Application of Self Organizing Map and SRTM data to characterize yardangs in the Lut desert, Iran

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ABSTRACT

Yardangs, an exclusive landform due to intensive wind erosion, cover a large area in the hyper-arid Lut desert of Iran. This paper presents a new approach using Self Organizing Map (SOM) as unsupervised algorithm of artificial neural networks for analysis and characterization of yardangs.

Nowadays, the Shuttle Radar Topography Mission (SRTM) with 3 arc sec data (approximately 90 m resolution) and nearly world wide coverage provides uniform good quality data.

The SRTM 3 arc sec data were re-projected to a 90 m UTM grid. Bivariate quadratic surfaces with moving window size of 5×5 were fitted to this DEM. The first derivative, slope steepness and the second derivatives minimum, maximum curvature and cross-sectional curvatures were calculated as geomorphometric parameters used as input to the SOMs. 42 SOMs with different learning parameter settings, e.g. initial and final radius, number of iterations, and the effect of random initial weights on average quantization error were investigated. A SOM with a low average quantization error (0.1040) was used for further analysis. Feature space analysis, morphometric signatures, three-dimensional inspection, auxiliary data like Landsat ETM+ and high resolution satellite imagery from QuickBird facilitated the assignment of semantic meaning to the output classes in terms of geomorphometric features. Results are provided in a geographic information system as thematic maps of landform entities based on form and slope, e.g. yardangs (ridge), corridors (valley) or planar areas.

The results showed that all yardangs and corridors were clearly recognized and classified by this method when their width was larger than the DEM resolution but became unrecognizable if their width is much smaller than the grid resolution. The identified yardangs and corridors are aligned NNW–SSE parallel to the prevailing direction of the strong local 120 days wind and cover about 31% and 42% of the study area respectively. The results demonstrate that SOM is a very efficient tool for analyzing aeolian landforms in hyper-arid environments that provides very useful information for terrain feature analysis in remote regions.

1. Introduction

The Lut desert or Dasht-e Lut in the south east of Iran is described as the “thermal pole of the Earth” (Mildrexler et al., 2006). With an area of about 80,000 km^2 it is regarded to the hottest and the driest desert in the world (Alavi Panah et al., 2007; Gabriel, 1938; Mildrexler et al., 2006). The eastern part of Lut desert is characterized by a great massif of dunes and sand rises, while the western part contains Yardangs, some of the world's largest desert forms separated by large wind-swept corridors (Walker, 1986). The yellowish-red Pleistocene clay deposits of the former Lut lake are now sculptured into straight bizarre shapes yardangs called *Kalut* or desert cities by the Iranian Baluchis up to 80 m high and 120 km long running in NW–SE direction (Gabriel, 1938). Alfons Gabriel, one of the first explorers in this area, describes this area as “In one row of “desert cities” after another *Kalut* stretch, probably in one uninterrupted formation, for about 100 miles in length and 25 miles in breadth (Gabriel, 1938, p. 199). He notes, “apart from sand dunes of the Lut, the *Kalut* were the most impressive sight we had ever seen” (p. 198).

Yardangs a Turkmen word used by the Swedish explorer Sven Hedin (1903) meaning ‘steep bank’ occur also on Mars and possibly on Venus (Goudie, 2007). They are streamlined forms up to 150 km long and 75 m in height resulting from a number of formative processes, including wind abrasion, deflation, fluvial incision, desiccation cracks, slumping, weathering and mass movement (Goudie, 2007; McCauley et al., 1977; Ward & Greeley, 1984). Wind erosion creates a streamline teardrop shape. Deflation and reverse air flow control the formation near the middle and downstream end. Fluvial incision due to occasional rainstorms may play a role in the early stages of yardang evolution, creating initial depressions along which wind can be channeled. Once established, the steep sides of yardangs may encourage mass movements to occur, whereas in playa environments salt weathering, wetting,

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and drying may contribute to preparing material for wind evacuation (Goudie, 2007). Yardangs show a considerable range in scales, from micro-yardangs (centimeter scale ridges), through meso-yardangs (few meters in height and length) to mega-yardangs that may be tens of meters high and several kilometers long (Cooke et al., 1993; Goudie, 2007; Halimov & Fezer, 1989; McCauley et al., 1977).

A limited number of morphometric investigations have been done on yardangs. Goudie (2007) identified mega-yardangs in hyper-arid environments with total rainfall less than 50 mm including central Asia, the Lut desert in Iran, northern Saudi Arabia, Bahrain, the Libyan Desert in Egypt, the central Sahara, the Namib desert, the high Andes and Peruvian desert. According to him, these features develop in a wide range of rock types e.g. sandstones, ignimbrites, limestones and basement rocks by a relatively unimodal wind direction. Yardangs occur in areas of sand transport rather than sand accumulation (e.g. Lut, Saudi Arabia, northern Namibia) and may have been shaped over millions of years (Goudie, 2007). Gutierrez-Elorza et al. (2002) studied the existence and generation of yardangs in the semiarid central sector of the Ebro Depression in Spain. They concluded that generation of yardangs in that area is related to the presence of playas, which constitute the source of abrading particles during dry periods. In another study Alavi Panah et al. (2007) used Landsat Thematic Mapper (TM) data to characterize land cover and surface conditions in Lut desert. They showed that the main land cover types of Lut desert could be differentiated by supervised maximum likelihood classification. However, their study was based on extensive time-consuming field work and Landsat data. The results depended on subjective decisions of the interpreter in selection of training areas. Inbar and Risso (2001) studied different size yardangs in the volcanic terrains of southern Andes in Argentina. They showed that micro and meso-yardangs are formed on ignimbrite flows but mega-yardangs are developed in the basaltic lava flows as long parallel corridors.

The NASA Shuttle Radar Topography Mission (SRTM) has provided Digital Elevation Models (DEMs) for approximately 80% of the earth's land surface. This enables more reliable analysis in many applications than before, especially in remote hyper-arid regions such as the study area. SRTM data is widely used for variable applications such as analysis of terrain characteristics (Falorni et al., 2005; Gorokhovich & Voustianiouk, 2006; Rabus et al., 2003) including volcano morphology (Wright et al., 2006) and large aeolian bedforms (Blumberg, 2006), vegetation studies (Kellndorfer et al., 2004), hydrologic modeling (Ludwig & Schneider, 2006) and morphotectonic analysis (Grohmann et al., 2007).

Geomorphometry is a quantitative technique to analyze land surface features. In simple terms, geomorphometry aims at extracting (land) surface parameters (morphometric, hydrological etc.) and objects (watersheds, stream networks, landforms etc.) using a set of numerical measures derived from DEMs such as slope steepness, profile curvature, plan convexity, cross-sectional curvature, minimum and maximum curvature (Fisher et al., 2004; Pike, 2000; Wood, 1996a,b).

In the past, manual methods have been widely used to classify landforms from DEM (Hammond, 1964). Automatic terrain analyses based on DEM are increasingly used in geomorphological studies mainly focused on morphometric parameters (Bue & Stepinski, 2006; Giles & Franklin, 1998; Miliaresis, 2001). Landforms as physical constituents of landscape may be extracted from DEMs using various approaches including combination of morphometric parameters subdivided by thresholds (Dikau, 1989), fuzzy logic and unsupervised classification (Adediran et al., 2004; Burrough et al., 2000; Irvin et al., 1997), supervised classification (Brown et al., 1998; Hengl & Rossiter, 2003; Prima et al., 2006), probabilistic clustering algorithm (Stepinski & Collier, 2004; Stepinski & Vilalta, 2005), automated classification using object-based image analysis (Dragut & Blaschke, 2006) multi-variate descriptive statistics (Dikau, 1989; Evans, 1972), double ternary diagram classification (Crevenna et al., 2005), discriminant analysis (Giles, 1998) and neural networks (Ehsani and Quiel, in press).

Self Organizing Map (SOM) is an unsupervised and nonparametric artificial neural network algorithm that clusters high dimensional input vectors into low dimensional (usually two-dimensional) output map which preserve topology of the input data. Preserving topology means that the SOM map preserves the relations between input neighboring points in the output space (Kohonen, 2001).

We used 90 m DEM produced from version 3 SRTM 3 arc sec data and the SOM algorithm for identification of yardangs in the western part of Lut desert. Hence, the major aims of this study are to:

- Provide a semi-automatic method based on morphometric parameters derived from 90 m DEM to identify dominant morphometric features in a hyper-arid region using SOM as an unsupervised neural network algorithm.
- Evaluate the effect of SOM training parameters on the quantization error and the selection of optimal SOM for identification of yardangs and other features.
- Examine the effect of random weight initialization on the quantization error of optimal SOM.

2. Study area

Lut desert (Dasht-e Lut, or Dasht-i Lut) is a low area of about 400×800 km^2 consisting of several large basins separated by low ridges (Krinsley, 1970; Walker, 1986). The desert fills low basins that stretch southward from the Khorasan province into the Kerman province between 29° 30' N and 30° 49' N, and 57° 47' E and 59° 53' E. The Lut desert depression contains several hundred meters of upper Pliocene to Pleistocene lacustrine silts over a basement of flat-lying Paleogene andesitic lavas and tuffs. Several Quaternary basalt flows occur near the Nayband fault on the western edge of the Lut. Further to the west the anticlinal ridges of the Shahdad thrust belt are formed of up to 3000 m of stratified marls containing gypsum, sandstone and conglomerates (Aghanabati, 1993; Sahandi, 1992; Walker & Jackson, 2002).

The eastern part of Dasht-e Lut is a low plateau covered with salt flats. This area consists of sand, and it contains some of the world's highest dunes reaching a height of 300 m (Krinsley, 1970; Walker, 1986). The study area with 6481 km^2 is located in the western part of Lut desert (Fig. 1) with strong diagonal lines resulting from wind erosion and episodic floods acting on the Neogene silts (Berberian et al., 2001). Altitude ranges from 100 m in the north and east to 404 m above sea level in the central and south eastern of the Lut desert. Slopes range from 0 to 19°. The Lut desert is characterized by a hyper-arid climate with an annual rainfall less than 10 mm (Fig. 2c) mainly falling in winter. The average mean daily temperature ranges from 11° in January to 40° in July. The mean annual wind speed is 6 m/s. The strongest winds start in April with average speed of 9.35 m/s (Fig. 2b). The prevailing wind known as “wind of 120 days” or *Bad-i-sad-o-bist roz Systan* running from NNW–SSE corresponds exactly to the direction of elongated yardangs (Fig. 2a).

3. Data and methods

The “Finished” SRTM data are currently distributed by USGS seamless ftp server (ftp://e0srp01u.ecs.nasa.gov/srtm/version2/SRTM3/). The finished SRTM data contain “no-data” holes where water or deep shadow prevented the determination of elevation. These holes are generally small, but render the data less useful, especially in hydrologic modeling which requires continuous flow surfaces (Jarvis et al., 2006). The version 3.0 SRTM data are the result of substantial post processing efforts of the original release SRTM data and are provided by the Consortium for Spatial Information (CSI) of the Consultative Group for International Agricultural Research (CGIAR). The data are distributed in a geographic (Lat/Long) projection, with the WGS84 horizontal datum and the EGM96 vertical datum and are currently available from the CGIAR-CSI SRTM database: http://srtm.csi.cgiar.org. The version 3.0 SRTM data represents an