Drone-based Digital Terrain Model for the classification of Karst topography texture.

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Abstract

Karst topography is represented in high spatial resolution digital surface models based on drones photogrammetry and Geographic Information Systems (GIS) methods to effectively describe, evaluate and quantify karst topography texture. The purpose of this paper is to delineate and qualified karst topography roughness zones in Jaj region of Lebanon.

The selected parameters such as Topographic Roughness Index (TRI), Fractal dimensions and Wombling method are combined and classified to form a karst topography zoning map.

The similarity of these parameters is tested in a correlation analysis; then combine together to forms the karst topography texture map. Besides orthoimages and site visits for the validation of the resulted map, a comparison with the generated Iwahashi and Pike landform classification raster prove the delineation in four karst zones: slight, moderate, high and very high textures.

Keywords: Karst, DTM, TRI, Fractal dimensions, Wombling method.

1. Introduction

In geomorphology, topography texture termed ‘grain’ and ‘roughness’, whereas amplitudes correspond to relief (Mark, 1975). The terrain analysis and modeling require the implementation of geomorphometry indices (Roughness, fractal dimension) incorporated into GIS to enhance the work of spatial analysts’ in the description of terrain topography.

Therefore, the objective of this project is to develop a new method based on

indices for terrain analysis that would delineate karst zones of different textures directly in a GIS environment.

Topography texture is essentially a function of the relative relief (elevation variation), recent innovations, interpret topography texture as a component of digital terrain modeling, Scale is also a significant factor influencing on topography texture depending on the spatial resolution of the dataset used and on the size of the study area. The dataset used is a Digital Terrain Model generated from drones aerial images with a high level of details and spatial resolution.

Although this study represents an important early phase of morphometric studies in Karst geomorphology.

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Until recently, there has been little quantitative application of Digital Terrain Models in karst geomorphology especially in a country like Lebanon full of karst limestones.

Morphometric studies in karst have a long history, beginning with the doline-shape analyses undertaken by Cvijic 1893. Meyerhoff (1938) examined doline size and distribution using geomorphometry as a tool, which is also a component of terrain roughness.

Day (1982) developed an additional general classification index, which analyzed different degrees of theoretical roughness and simulated overall karst landscapes.

Brook & Hanson (1986, 1991) used morphometric analysis to model karst terrain and to assess the potential of morphometry in karst types.

Lyew-Ayee (2004) combined roughness calculations with specific landform morphometry to obtain multiscale quantitative indices of the karst landscapes.

This paper will discuss a methodology for the classification of karst topographic texture into different zones based on morphometric indices.

The topographic texture is among the general quantitative descriptor of the landforms through exogenetic processes (Demek, 1972). In this case, texture indicators employed in the modeling of karst terrain include terrain roughness index, fractal dimensions, and the Wombling method.

Karst topography texture is a function of the inherent characteristics of a karst surface affected by weathering, glaciation and the overlying soil cover.

Measures of surface roughness and fractal dimension have been employed for the explanation of karst terrain complexities and the Wombling method for karst texture zoning.

Field measurement of karst landscape is arduous and time-consuming, drones photogrammetry, provide sufficiently detailed information about karst topography texture by Digital Terrain Models (DTM) and Digital Ortho Mosaics (DOM).

Surface roughness is an important mathematical descriptor of karst terrain, and the combination of drone-based Digital Terrain Model (DTM), GIS software has brought new understanding, particularly to poorly mapped karst terrains. The number of surface roughness studies in karst will increase and geomorphologists will be able to delineate karst texture and type.

2. Materials and methods

The study area located in the Jaj region (Lebanon), a mountainous area in Jbeil district, that extends geographically between the two rivers " El Jaouz" in the North and "Ibrahim" in the South. It stands on average altitude above the sea level of at 1800 meters in very steep terrain (Ghanem, 2018).

The outcropping rocks of the study area belong to the Middle Jurassic of the Secondary Era and composed of dolomitic limestone. Jaj region receives a precipitation average of 1500 mm per year, mostly in the form of snow. The summer is dry with average temperatures of around 20 degrees, rainy and snowy winter with average temperatures in February of 3 degrees.

The karst of the Jaj region is characterized by smooth to very rough terrain in somewhere very extreme and inaccessible for pedestrians, it is constituted from different kinds of lapies and large towers and a big number of sinkholes of various types (Ghanem, 2018).

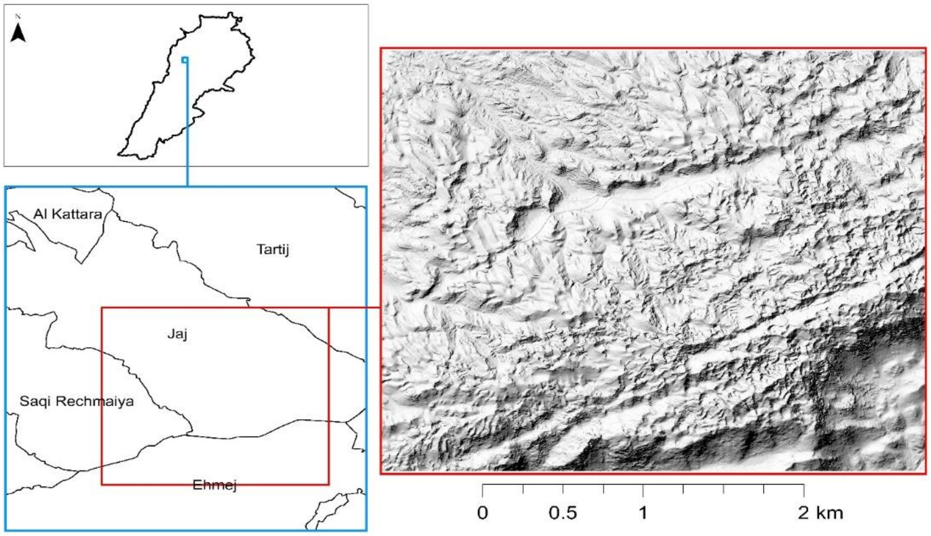

Fig.1.Study area and the hillshade of the Karst topography

Due to the difficulty of walking on Jaj terrain the fastest and optimal way to survey the karst was the use of drones and photogrammetry.

Aerial images acquired by the drone for the study area in the Jaj region comes from a built-in camera of 20 megapixels from a DJI Phantom 4 pro. The workflow used to create a high-resolution Digital Surface Model and an orthomosaic of the study area is divided into three main parts: (1) field data acquisition, (2) photogrammetry data processing, (3) data interpretation and GIS analyses.

The first part is the project planning, it includes pre-flight preparation to understand which flight height is suited to our needs, the area covered and the flight path. As our study area occupied 8 square kilometers with an elevation interval ranging from 1290 m to 1983 m above the sea level. It was impossible to fly this huge area with a Phantom 4 pro in one mission because of the low endurance of these drones, to solve this problem, the project was divided into 16 flight missions each of them covers 0.5 kilometers. For a precise positioning of the generated datasets (DSM and ortho models) in a Geographic Information Systems (GIS), we placed a minimum of five Ground Control points (GCP) for each of the 16 flights missions and measured with a differential GPS with a positioning accuracy of 1 cm in the stereographic coordinates system of Deir Ez Zor.

The drone flew at an average altitude of 150 m following a trajectory designed and controlled automatically using an application of Dji ground control station. In the 16 flight missions, 7712 images were taken during the acquisition process with an overlap of at least 80% between the sequential photographs and 70% lateral overlap covering a total study area of 8.8 sq.km.

During the development phase, each of the 16 missions was imported into the Agisoft Photoscan Professional photogrammetry software for data processing. Every two missions were processed together in one chunk because the PC could not process all the 7712 images together, then the processed chunks were processed to form the whole study area.

After georeferencing, a dense point cloud containing millions of points of known X, Y, and Z locations was created from the stitched photographs. These points then meshed in a Triangular Irregular Network (TIN). The TIN was created and converted into a digital surface model (DSM) with a spatial resolution of 15 cm.

The alignment of aerial images and ortho-rectification with the Digital Surface Model (DSM) helped us to generalize orthophotoplan with a high spatial resolution of 4 cm.

Let's note that the geo-treatment of the 16 missions gives an output of 8 DSMs and 8 orthophoto plans, the 8 DSMs were also loaded into Quantum GIS (QGIS) and combined to form a mosaic of DSM of the entire study area Figure 2a shows the mosaic of Digital Ortho Model (DOM) and figure 2b the DSM.

To reduce interpolation errors in DSM we resampled in a cartographic generalization the spatial resolution from 30 cm to 1 m and we passed a 3 X 3 filter for noise reduction, and to transform the DSM to a Digital Terrain Model (DTM), we cropped the vegetation cover (scattered Cedars trees) and interpolate the elevation data of the neighborhood to for a new bare land DTM.

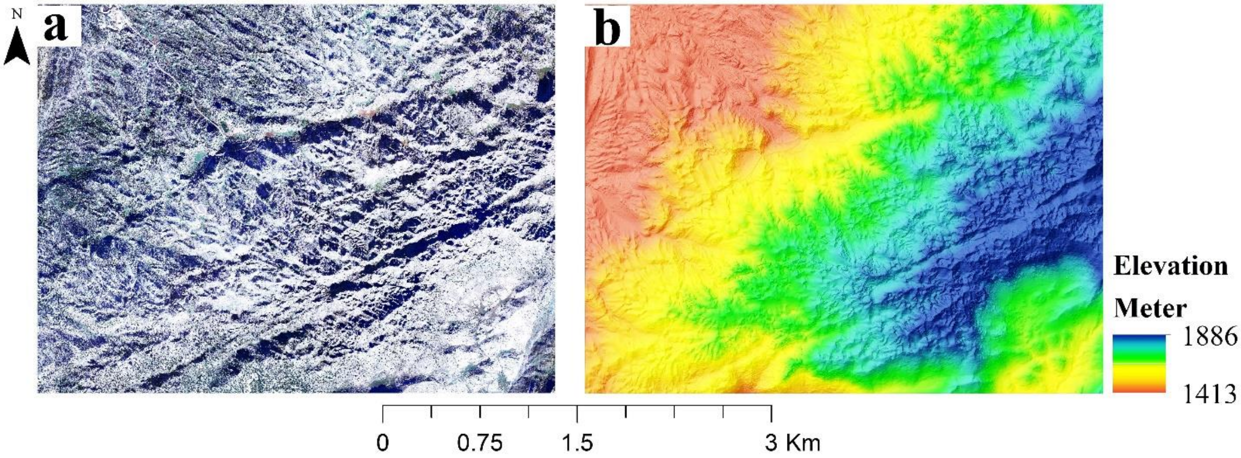

Fig. 2. Aerial generated Data sets a) Digital Ortho Model b) Digital Terrain Model

The delineation of the karst topographic texture is depending on terrain smooth and rough zones. In morphometry there are several methods for determinations of topographic texture, Riley et al 1999 used the Terrain Roughness Index (TRI) to calculate the roughness surfaces, Eastman (1985) developed the fractal dimension index to measure the irregularity of patterns, Womble (1951) determines boundaries (barriers) that separate areas of lower and higher values.

The methodology used in our study depends on terrain roughness, irregularity, and barriers.

TRI calculated the sum change in elevation between a grid cell and its eight neighboring grid cells by squaring the eight differences in elevation, summing the squared differences, and taking the square root of the sum (Riley et al 1999).

The irregularity and fragmentation of karst were quantified by Eastman (1985) technique for measuring the fractional dimension based on the slope calculation following formula 1:

$$D = \frac{\log(2)}{\log(2) + \log(\sin(\frac{180 - slope}{2}))} \qquad (1)$$

For determining barriers of abrupt changes in karst textures, the Wombling technique separates areas of lower and higher values of a georeferenced unit (Fortin and Dale 2005).

The magnitude of the spatial change is done by averaging the absolute derivative of the surfaces, the zones that exhibit high rates of change are those corresponding to high values are also called barriers.

To highlight these barriers an information matrix between corresponding surfaces should be introduced, each approximated surface is subdivided into:

$$n \times m = N \text{ pixels} \qquad (2)$$

Where n and m designate the number of pixels on the sides of a rectangle containing the surfaces approximated. In each of the N pixels, a first-order polynomial is fitted, written f(x),
Where X=(x,y) represents the coordinates x and y designating, respectively, the longitude and latitude, and the value of the partial derivatives are computed in the center of the pixels (Barbujani et al.).

$$a = \frac{\partial f(X)}{\partial x} \text{ and } b = \frac{\partial f(X)}{\partial y} \qquad (3)$$

For the unification of the values of the generated morphometric parameters, a fuzzy membership applied on TRI, fractal dimension and Wombling technique to reduce the values in an interval between 0 and 1 from low to high.

The three fuzzified rasters were combined in GIS software to give the karst topographic texture in a form of the raster dataset.

For the initiation and validation of the topographic texture classes comparing to landforms, the DTM of the study area was classified with Iwahashi and Pike unsupervised method on only three terrain attributes: slope gradient, surface texture and local convexity (Iwahashi and Pike 2007).

3. Discussions and results

The terrain datasets generated from drone photogrammetry, Digital Orthomodel (DOM) figure 2a and Digital Terrain Model (DTM) figure 2b shows the complexity of karst terrain and highlight their linear forms (faults and lineaments) figure 2a, the elevation amplitude varying in an interval from 1413 to 1886 meters above the sea level.

The three karst topography characteristics, roughness, irregularity, and barriers expressed by geomorphometry parameters, TRI, fractal dimensions and Wombling method of figure 3a, b, c highlight terrain texture.

Visually the three parameters, TRI, fractal dimension and Wombling method are very similar in figure 3, they appear the karst forms and structures in different levels of details. Figure 3a of TRI shows the extreme roughness of the karst terrain with a maximum value of 5.5, the fractal dimension higher values of terrain similarity of 2.7 expressing a very complex shape figure 3b. Figure 3c of the Wombling method with a higher level of details showing the barriers between karst types at a maximum high value of 1.4.

The same karst structures highlighted on the three geomorphic parameters are shown on the DOM of figure 3d and recognized by their shadows. To more understand the similarity between geomorphic parameters the result of the correlation analysis between TRI and fractal dimension R^2= 0.95, Wombling method and fractal dimensions R^2= 0.93 and Wombling method and TRI R^2=0. 91. Following the correlation results and the visual analysis, we can conclude that geomorphic parameters of the study area are proportional and very similar with some differences in the level of details.

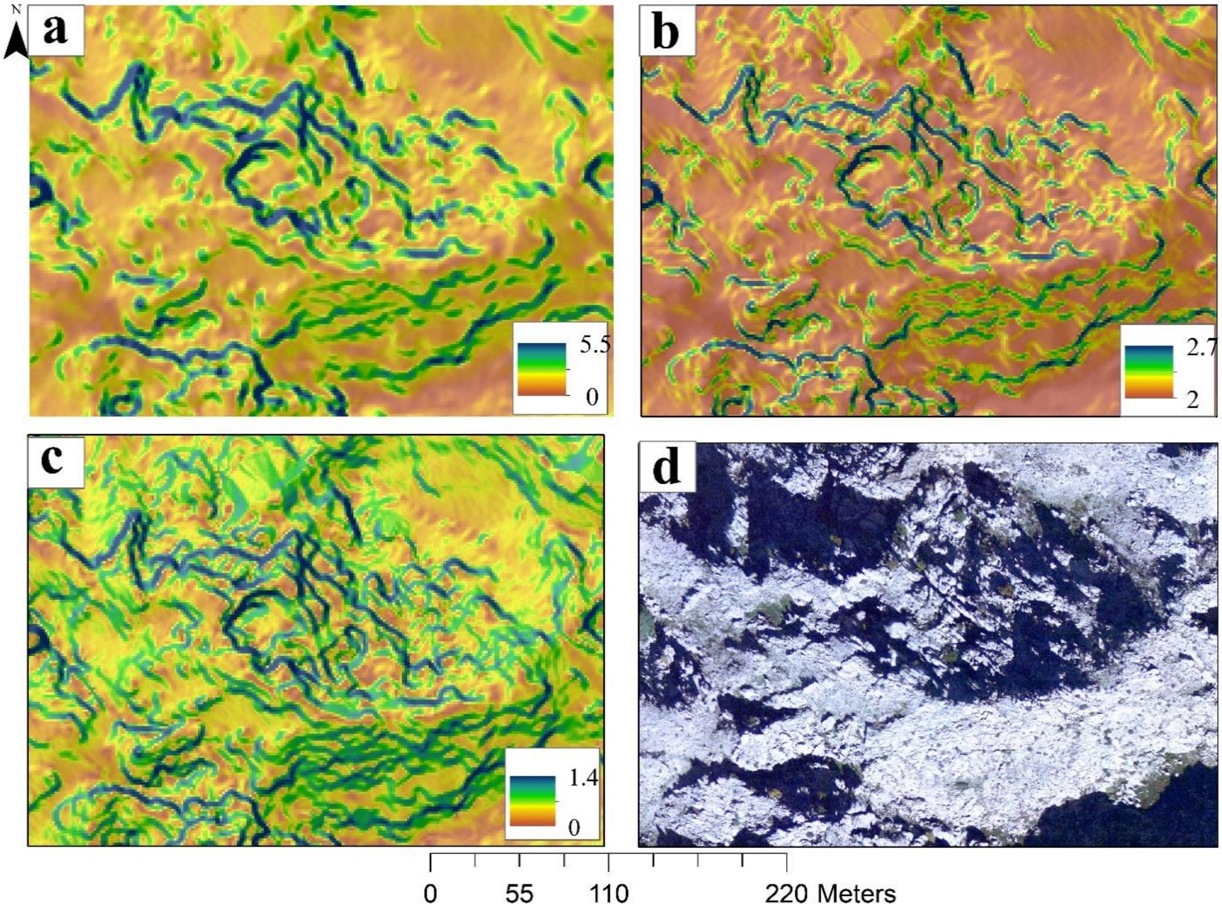

Fig.3. Karst Topography texture, a) TRI, b) Fractal dimensions, c) Wombling method, d) Digital ortho model.

To include this level of detail or the small difference between the geomorphic parameters to the topographic karst texture map, a unification of values based on the fuzzy logic operation was applied to the raster dataset of the geomorphic parameters then the three generated fuzzy rasters were combined to form one map of topographic karst texture values.

The topographic karst texture map classified into four zones by the application of geometrical interval method to form a final topographic texture zoning map figure 4, the four karst texture zones begins from slight textures which occupied 22 % from the whole study area, moderate texture 27%, high texture 26% to a very high texture 26%.

From this percentage of areas, we can conclude that Jaj karst is a high topography texture karst, to validate the result of figure 4 we draped the map of Iwahashi and pike landforms generated from drone DTM and we add new designations for the four zones a follows:

Table 1: Jaj karst topography texture and Iwahashi and Pike classification

	Topography texture	Iwahashi and Pike classification		
Zone 1	Slight texture	Gentle slope	Fine texture	Low convexity
Zone 2	Moderate texture	Gentle slope	Fine texture	Low convexity
Zone 3	High texture	Steep slope	Coarse texture	High convexity
Zone 4	Very high texture	Steep slope	Coarse texture	High convexity

Table 1 shows the result of the topography texture of Jaj karst classified into four classes and compared to Iwahashi and Pike landforms give the same designation and characteristics.

The karst slope of the first two zones is gentle due to the low convexity of the terrain otherwise zone 3 and 4 high texture and high convexity figure 4.

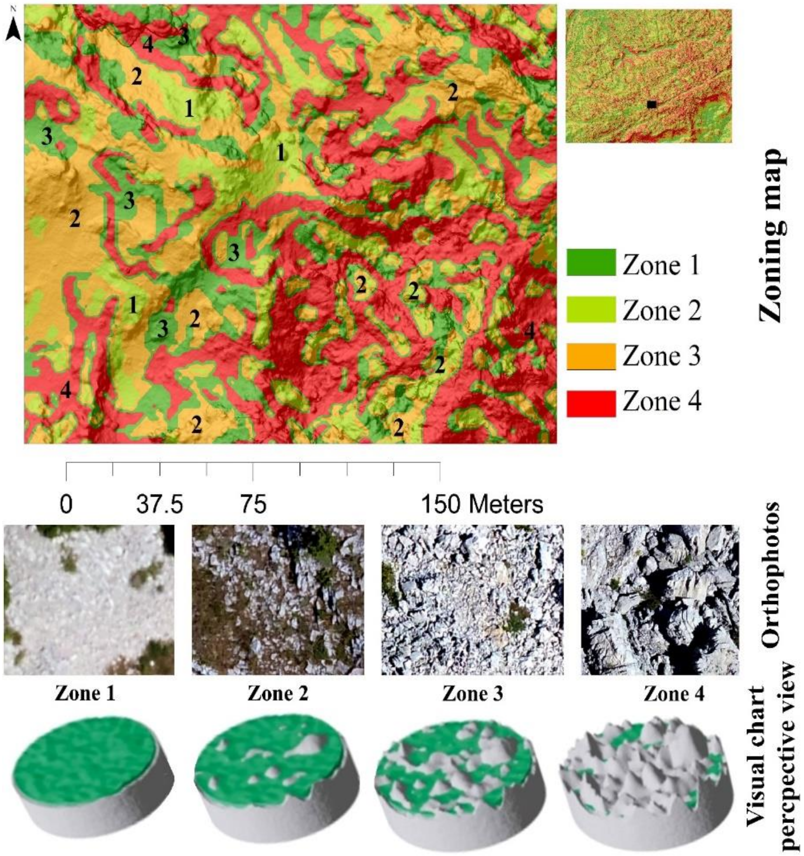

Fig. 4. Zoning map of karst topography texture, drone orthophoto of karst zones and a visual chart for rating karst topography from slight texture zone 1 to very high texture zone 4 in a perspective view.

The zoning map of Jaj karst topography texture of figure 4 englobe in each zone the form of karst related to the high-resolution orthophotos and to more understand the karst form the chart of perspective view comes to show the image of these zones.

Besides aerial images site visits are made for the definition of the four karst topographic texture as Zone 1 includes sinkholes, hutches resulted from old gelifications processes or small smooth lapies.

Zone 2, small lapies of maximum one-meter height

Zone 3, Medium lapies ranging from 2 and 5 meters' height.

Zone 4, Karst towers with more than 5 meters' heights

4. Conclusion

Drones photogrammetry and GIS technology gave a new dimension to karst terrain analysis and modeling.

In this paper, we introduced a new method for delineating karst topography texture from digital terrain analysis. This study tested new parameters based on drones generated Digital Terrain Models and Ortho models for karst terrain analysis applied to the Jaj region. The methodology of terrain analysis introduced in this paper is a valuable resource application to any natural resource variable of interest. The results indicated that Jaj karst topography texture varies from slight to complex. Jaj karst topography texture was classified into four zones and compared with Iwahashi and Pike landforms for validation, then defined as Karst landforms from aerial orthoimages and by a site visit.

The result of the method applied in this paper is important in mapping the shape of karst limestone and it could form an educational material for identifying karst topography texture.

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