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USING HIGH-RESOLUTION DIGITAL SURFACE MODELS AND GIS-BASED GEOMORPHOMETRY TO DRAW A KARST LANDFORMS MAP

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Abstract

Karst ecosystems are among the most distinctive landscapes on the planet, and they have piqued scientists' interest for decades. Karst areas have a distinct surface topography that can be defined by karst towers and dolines. Drones are used to perform a detailed study of karst terrain, high-resolution Digital Surface Model and Digital morphometric techniques focused on GIS to determine the structure of certain terrain and provide additional knowledge for karst landform modeling.This paper discussed a technique for studying karst landforms in Jabal Jaj. The results indicate that karst tower blocks and depressions may be categorized based on their morphometric parameters and are the keys of a detailed karst landforms map.

Keywords- Karst tower blocks, depressions, DSM, SVF

1. INTRODUCTION

Quantitative descriptions of karst landscape forms are needed for mapping and classifying terrain, interpreting its origins, and testing mathematical models of landform genesis, the availability of digital terrain data has attempted to develop morphometric indices to delineate karst forms.

In this paper, morphometric indices for internally drained karst topography are established and applied to Jabal Jaj karst in Lebanon, morphometric parameters dependent on terrain and its properties for karst landscapes qualitative description. Quantitative karst landscape mapping has now resulted in a better understanding of certain terrain, allowing for more detailed classification and comparison. However, most analyses rely on a limited set of field survey measurements or obtained from topographic maps. Sawkins (1869) and Sweeting (1972) were among the first scientists to describe karst terrain topography as hills and depressions. Corbel and Muxart (1970) regarded kegelkarst as being tower karst (Sweeting 1972). According to Day (1978), "of all the known karst models, has sparked by far the most interest, research, and debate." Karst forms ‘depressions’ and ‘karst tower’ denote two very different landforms, with depressions being characterized by deep enclosed forms distributed throughout the terrain, while karst towers are typified by long vertical shapes or peaks separated by narrow interconnected depressions. Morphometric analysis of karst characterizes, describe and model different karst landscapes. Brook & Hanson (1991) used terrain analysis to model karst terrain and to assess the potential of morphometry in distinguishing karst types. Tower karst and depressions are irregular, through which water is conducted underground, they are distinct from each other.

On a contour map of a karst region, circular contour lines indicate depressions as negative relief components, while narrow concentric circular contour lines indicate positive relief features.

Lehmann (1958) described the geomorphology of tower karst as less widespread than cockpit karst and towers karst are steep-sided hills that slope up to 60°, they have a subconical form, though many have flattened tops. Many karst tower bases are undermined associated with foot-caves and springs.

The fast evolution in technology and data, such as laser scanners, drone photogrammetry, and high-resolution digital elevation models (DEMs) – now enable a detailed analysis of karst terrain (depressions and tower karst).

This paper outlines an effort to measure the karst landforms of Lebanon's Jaj area by studying the morphology of karst tower and depression terrain using geographic information systems (GIS)-based morphometric techniques in a digital representation of the karst landscape and prompts a re-evaluation of many assumptions about karst terrain.

We digitally analyze Jaj karst terrain at the scale of individual landforms based on drones' high-resolution Digital Surface Models (DSM) to distinguish different types of karst areas.

The digital morphometric techniques described in this paper provide a basis for the analysis of other karst regions around the globe and put a new methodology in drawing karst landforms maps.

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2. MATERIALS AND METHODS

Jaj mountain extends geographically between the two rivers of "Nahr El Jaouz", to the north, and "Nahr Ibrahim", to the south. It is held at an average altitude of 1800m above Sea Level.

Jaj mountain geology is a part of a coffered anticline massif belong to the Middle Jurassic of the Secondary Era limited from the West by the western flexure of Lebanon and to the East by a local flexure the "Oriental flexure of Jaj mountain".

The study area receives an average precipitation of 1,500 mm per year, mostly in snow. The summer is dry with temperatures of around 20 ° C, on average, for August and the winter is rainy with temperatures of 30° C for February.

Jaj mountain karst presents well-developed "surface manifestations" (different kinds of lapies and large towers and an infinity of dolines of various types) and a very rich "buried Karst" with about twenty chasms and snow pits (Ghanem, 2018).

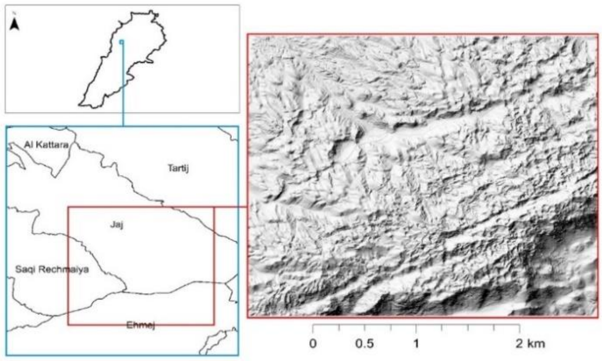

Figure 1 The hillshade Karst topography of the study area

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

Drone Aerial images acquired from a built-in camera of 20 megapixels of a DJI Phantom 4 pro. The whole project process is divided into three main parts: (1) aerial image acquisition, (2) data processing, (3) geomorphometry analyses.

The first part of the mission planning includes pre-flight preparation (flight height, flight path, area covered, etc…). It was impossible to finish the project in one flight mission due to the low endurance of these drones and to the big elevation interval of the study area, that is why the project was divided into 2 flights. The generated DSM and ortho models were geometry corrected by nine Ground Control points (GCP) measured with a differential GPS with a positioning accuracy of 1 cm in the stereographic coordinates system of Deir Ez Zor.

At a flight height of 150 m, both missions acquire 1007 frames covering an area of 1.4 square kilometers with an overlap of 80% between the sequential photographs and 70% lateral overlap.

In the second part of data processing, all aerial frames were imported into the Agisoft Photoscan software for image processing and generation of high spatial resolution DSM, 16 cm, and an orthomosaic of 4 cm.

The Morphometric analysis part of depressions and karst towers delineation in GIS environment based on the drone generated high-resolution Digital Surface Model (DSM).

Depression's delineation methods

Sinks are closed depressions that exist in digital models; others are objects found in flat environments, and their number declines as the spatial resolution increase. Depression's identification begins from sinks removal following by a mean focal statistics filter to reduce pits and artifacts. Different depressions, like the karst enclosed one, are determined by the disparity between the original DEM and the filled one.

The delineated depressions were transformed into polygons showing both natural features and pits from surface imperfections (Doumit & Awad 2020).

Karst blocks identifications

For karst blocks identifications the Difference from Mean Elevation (DFME) defined by the neighborhood size as the mean elevations for each tested scale at each grid cell in an input digital elevation model (DEM). Neighborhoods are based on the square regions 3 x 3 with maximum tested search radius (rmax):

$$r_{max} = \text{floor}\left[\log_B \left(\min\{Col / 2, R / 2\}\right)\right] \quad (1)$$

Where *B* is the base value and *C* and *R* are the number of columns and rows in the DEM respectively. The base value determines the density with which the range of scales is sampled. The default base value is 1.5 and $1 < B \leq 2$. The series of neighborhoods of dimensions' *s* x *s* is given as:

$$s = 2 \times \text{floor}(B^i) + 1 \quad (2)$$

for $0 \leq i \leq r_{max}$. and repeated values, which can occur for small values of i and B are removed from the series.

The DFME is then defined as the proportion of the tested scales for which the grid cell's elevation is higher than the mean elevation, it measures the relative topographic position of karst block as a fraction of local relief, and so is normalized to the local surface roughness (Lindsay 2018).

Karst tower selection

Karst peaks and pits occur in the identified karst blocks as concentric isolated contour lines ranging from 1 to 10 meters' height or depth. To separate peaks and pits we used the Sky View Factor, the sky view factor (SVF) defined the visible sky above a surface (Zakšek et al. 2011). Therefore, SVF can be the ratio of the visible sky that can be seen from a location in karst blocs to the whole skydome containing visible and obstructed sky.

The light projected onto a location on the DSM is generally associated with the sky visible at this location. For example, the peak of tower karst is brighter than the karst deep pit because it receives more illumination from the surrounding sky.

The calculation of SVF is to measure its angle, which represents the projected area of the hemisphere over the location in a unit of space.

The angle γ_i is computed by observing the horizon vertical elevation in a chosen n number of directions.

The SVF is calculated in the following equation (Zakšek et al. 2011).

$$SVF = 1 - \frac{\sum_{i=1}^{n} \sin \gamma_i}{n} \quad (3)$$

SVF ranges between 0 no sky is visible (karst pit) and 1 the entire hemisphere is visible, the areas with high SVF are defined as karst towers.

3. RESULTS AND DISCUSSIONS

The generated orthomosaic figure 2a shows the limestone pavement and karst structures and the DSM figure 2b with elevation interval ranging from 1417 meters to 1848 meters above the Sea level gives a detailed 3d perception of the karst forms.

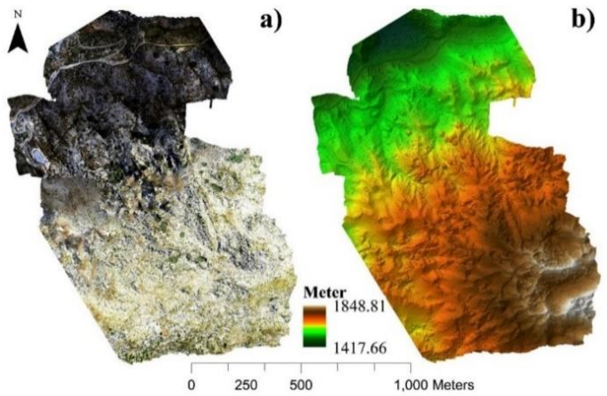

Figure 2 Photogrammetry results a) orthomosaic b) DSM

The drone generated DSM beside karst structures and form contains Cedars trees from different sizes and shrubs. The vegetation cover of a DSM should be neglect an edge detection filter applied to the ortho model and 0.5-meter contour lines interval generated from DSM was used to isolate vegetation from karst structures figure 3.

The high-resolution DSM with GIS algorithms constitutes the skeleton of the karst depressions and towers geomorphometry study.

The morphometry of karst depression

In the study area, 102 depressions were delineated (figure 4a) from various forms and sizes with a minimum area of 10 square meters to the biggest depression of 25000 square meters.

Depressions depth varies from 2 meters to 33 meters, most of the delineated depressions have elongated forms with major axes lengths varies from 18 meters for the small depression to 3.6 kilometers for the biggest one.

The morphometry of karst towers

For the generation of the karst tower map, the calculated Difference from Mean Elevation from formulas 1 and 2 of figure 3a shows karst deep areas (pits) in dark color with a value of zero and the karst high blocks in bright colors with a value of 1.

Based on the DFME generated raster 12214 karst blocks were identified beginning from a small rock of one-square meter area to big karst structures of 44151 square meters.

The SVF map of figure 3b highlights negative values and dark colors of deep narrow pits which could be chasms, in both DFME and SVF raster karst towers took the higher values.

The similarity of raster values between DFME and SVF figures 3a and 3b allowed the combination of the two models in one raster figure 3c joining karst blocks from DFME and the karst pits from SVF.

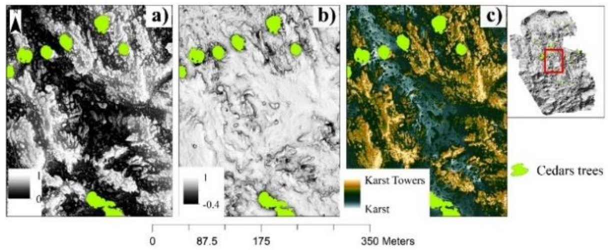

Figure 3 (a)DFME raster b) SVF raster c) generated karst tower and pits raster

A satisfactory validation result of the towers karst map of figure 3c was made using a high-resolution GPS field survey of the major karst towers and closed-loop contour lines with an elevation interval of one meter. High karst cones figure 4 with high DFME and SVF values are represented by concentric closed contour lines.

Figure 4 High karst tower (cone) in the study area

The resulted towers karst map of figure 3c identified 845 karst cones from different heights ranging between one to 10 meters and 473 karst pits some are open leading to the groundwater reservoir.

The morphological measurements of karst tower blocks and depressions depth and forms indicate several aspects of geomorphic variation between them. First, the overall areas and the total perimeters of karst tower blocks exceed those of karst depression. Second, the tower karst displays more complex forms than depressions karst, as reflected in figure 6, the longer axes of most tower blocks are oriented W-E to E-W, whereas the depressions are mostly oriented in a broader arc N-S to S-N figure 5. Depressions are smoother shaped than the tower blocks, with the tower blocks having greater shape irregularity.

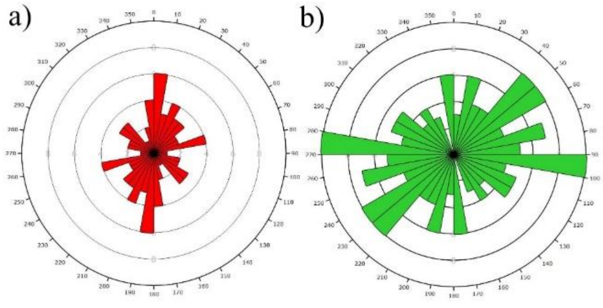

Figure 5 a) Rose diagram of depressions axes orientation b) rose diagram of tower blocks axes orientations.

The orientations of most depressions' axes are North-South figure 5a, otherwise, karst towers block axes orientations are East-West.

The orientation of depressions axes is perpendicular to the orientation of the karst block, these blocks were subject to tectonic, climatic and erosion factors which changed in their forms and shapes with the appearance of cones and pits figure 4. The extracted cones and pits from the karst blocks elevation model were added to the karst landforms map of Jaj.

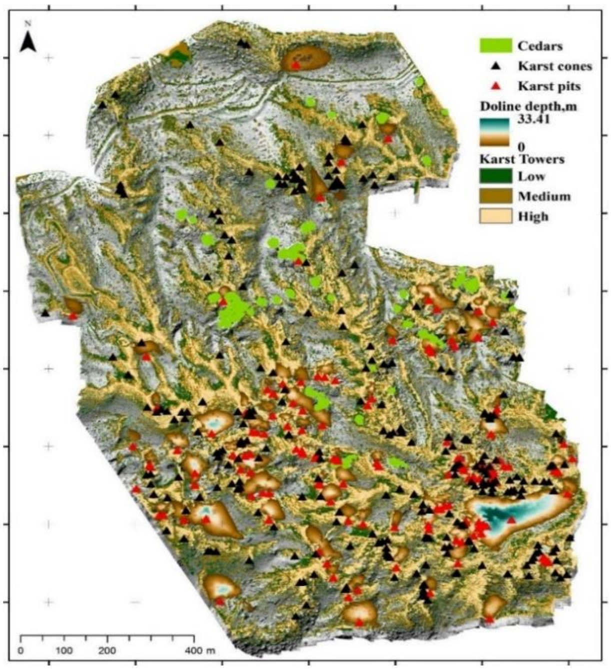

Figure 6 Detailed Geomorphological map of Jaj karst

The result was the karst landforms map of Jaj figure 6, it is constituted from a hillsahde background, highlighted cedars trees extracted from the orthophotoplan, showing karst dolines with their depth generated from the high-resolution DSM, classified karst blocks into low medium and high proportional to their height and shows the spatial position of karst cones and pits.

4. CONCLUSION

To distinguish the karst landforms, geomorphic classification of tower karst and depressions using GIS and photogrammetry was used. The findings indicate that in karst surface extraction, using high-resolution DSM rather than ortho models is a viable way to prevent shadow problems and misclassification. This approach of drones' high-resolution DSM is cost-effective compared to other solutions as LiDAR and remote sensing imagery.

Terrain analysis was used to derive morphological parameters of tower blocks and depressions, which offered a simple way to quantify geomorphic attributes of karst landform groups. Morphological analysis indicates that karst tower blocks and depressions have significant morphometric variations in terms of area, perimeter, roundness, and orientations.

The resulted karst landform map could form a good teaching material and could be a foundation of future erosion and tectonic research in Jaj area.

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