Drone-Based DSM For Multiscale Geometrical Characteristics Of Ephemeral Gullies.

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Abstract: The advance uses of drones in geosciences by producing very high spatial resolution Digital Surface Models (DSMs) and Digital Ortho Models (DOM), at various flight heights, led to different digital models scales. Relief plays an important role in the formation of Ephemeral Gullies (EG), this study focuses on the prediction of multiscale EG location using the compound topographic index (CTI) and analyzed their geometrical characteristics as length, depth and volume of the three different spatial resolutions DSM processed from different drone flights height. Ephemeral Gully extracted from the three flight heights of 120, 240 and 360 meters were compared with each other to understand the effect of generalization at different scales. The results highlight the presence of two scales, small scale ephemeral gully expressed by the flight height 240 and 360 m and a much smaller scale in the level of micro relief of the flight height 120 m.

Keywords: drone, ephemeral gully, CTI, DSM, Multi-scale.

1. Introduction

The appearance of drones and the very fast evolution in close range photogrammetry and their applications for digital surface extraction leads to multiscale high-resolution terrain analysis. The scale is predominantly considered as a function of the resolution of Digital Surface Models (DSM) [12, 15]. Pike et al. (2009) remarked that no digital elevation models derived map is definitive, as the generated parameters differ with algorithms and can vary with resolution and scale [7]. Soil erosion from water runoff occurs predominantly by three processes: sheet erosion, rill erosion, and ephemeral gullying [8]. Doumit and Awad (2019) analyzed the effect of multiscale DEM on the delineation of sheet and rill erosion whereas in this paper we focus only on ephemeral gullies (EG) erosion based on a multiscale drone based DSM. Ephemeral gullies are small channels eroded by concentrated flow in the same location due to subsequent runoff events [3]. Time series aerial photography and DEM were used to map gully erosion [19,24,22,26]. More recently, drone-based close-range photogrammetry and structure from motion (SfM) including different spatial scales have been used in geomorphic studies, [14, 29, 30,9]. Close range photogrammetry is based on computer visualization tools for three-dimensional surface reconstruction algorithms. Structure from Motion (SfM) creates massive point clouds based on pixel matching from which highly accurate digital surface models (DSM), and orthophotos can be derived [9,14]. Several studies have documented the relationship between ephemeral gully formation and runoff erosivity using terrain derivatives, especially drainage area and local slope [23,25,17]. From the terrain derivatives, stream power is widely used to identify the location of ephemeral gullies which depends on “generation of concentrated surface runoff of sufficient magnitude and duration to initiate and maintain erosion, leading to channelization” [27,6]. Plan curvature provides the measure of the degree of flow convergence along a flow path leading to an ephemeral gullies formation models [32]. Zevenbergen (1989) describes five factors as influencing ephemeral gully formation including:

1. Overland flow discharge and duration;
2. Slope and flow depth determining the magnitude of the flow’s downslope;
3. Planform curvature determining the convergence of the flow;
4. Soil characteristics determining the erodibility of the soil;
5. Vegetation characteristics, reducing the soil susceptibility to erosion [31].

This study is based on drone DSM multiscale and it focused only on topographic controls of overland flow influencing on ephemeral gully development taking into account only the first three Zevenbergen’s terrain factors: discharge, slope and plan curvature, which is the basic key of topographic controls in ephemeral gully formation process [27]. Plan curvature as second terrain derivative contributes to ephemeral gully formation in multiple ways, a) Convergence runoff and discharge are related to slope length to a power greater than unity [31]. b) plan curvature degree determines local flow geometry and the degree of flow concentration. c) plan curvature represents the degree of concentration of stream power. For the identification of ephemeral gullies, Thorne et al. (1986) used these parameters to calculate a Compound Topographic Index (CTI). Parker et al. (2007) tested the CTI model to predict ephemeral gullies locations in a GIS environment for different sites. Moore et al. (1988) used two methods to estimate EG location: the slope area index and the wetness topographic index, Casalí,.et al. (2006) tested several methods for estimating ephemeral gullies and concluded that CTI is probably the most widely used approach for predicting ephemeral gullies location. After we presented the fact of the studies concerning the identification of ephemeral gully erosion, we submit the specific objectives of this study were:

- to apply the work carried out by Zevenbergen and Thorne, utilizing Geographical Information Science (GIS) for multiscale ephemeral gullies delineation from CTI parameters.

- compare and evaluate the impacts of multiscale expressed by drone flight heights on ephemeral gullies geomorphological parameters (length, depth, and volume).

2. Study area

Our project is situated in the western chain of Mount-Lebanon in Zaarour region with an area about 15 hectares, Mount-Lebanon forms a barrier against the rain movement and the precipitations that can reach more than 1400 mm per year [28].

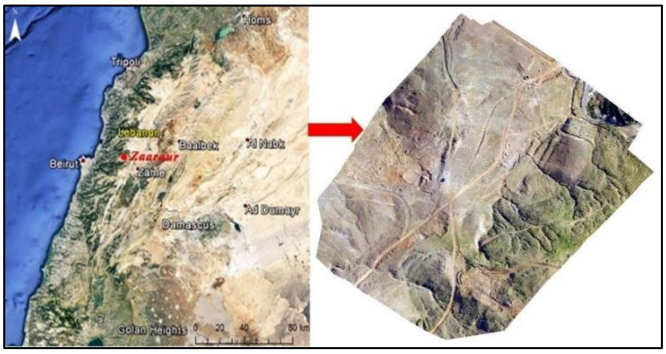

Figure 1: *Google Earth Spatio-image of Lebanon and an orthophoto of the study area.*

The study area is characterized by several geological formations from the second era with the eroded and permeable formation of the Cenomanian (C_4), Upper Aptian (C_{2b}) Albian (C_3), Lower Aptian (C_{2a}) and Neocomian (C_1) shows effective physical water erosion.[10]. Zaarour area is characterized by light soil and mostly covered by sandy and grayish clayey soils and very limited surfaces of limestone. Erosion and runoff are considered to be effective in sandy soils [11].

3. Material and methods

A DJI Phantom 3 drone, caring a camera of 14 megapixels flew the study area capturing aerial images at different flight heights; the experiment constituted from 3 flight missions of 120,240 and 360 meters' height (FH-120, FH-240, and FH-360). Flight planning was designed in a mobile application called DJI ground station, which is based on google maps images, the datum of flight heights was the same from the drone takeoff point for all missions. The flight path followed by the UAV was identical for all the flights FH-120, FH-240, and FH-360, after drawing flight paths for all missions, in DJI ground station application, the camera shutter interval was set at 2 seconds. The acquired images overlapping was set at 80 % and side lapping at 70%. The photogrammetric processing of the flight missions was completed in Metashape photoscan, a Russian photogrammetric software. The processing workflow begins with the stitching of derived aerial images, then the production of point clouds, 3D mesh interpolation, Digital Surface Model (DSM) and Digital Ortho Model (DOM) generations. Throughout the assessment, we comprehensively used this drone for aerial images acquisition to the generation and interpretation of Digital Surface Models (DSM) and Digital Ortho Models (DOM) by applying structure from motion technology. A three processed DSM and DOM from different flight heights with several spatial resolutions, FH-120 of 120 meters' flight altitude with a high resolution highlighted all the terrain details even rocks texture, passing by FH-240 the terrain is smoothed with some concave and convex areas and ending by FH-360 a very low spatial resolution and a very smoothed terrain of 360 meters' flight height.

Table 1: *DSM and DOM spatial resolution at different flight heights.*

Flight height	120 m	240 m	360 m
DSM	10 cm	20 cm	30 cm
DOM	5 cm	10 cm	20 cm

As per table one different flight altitude lead to different spatial resolutions (pixel size), as per the photogrammetry law more the flight height is high more the scale is small, the minimum spatial resolution for DOM is 5 cm which expresses a high level of details showing ephemeral gullies traces and 10 cm DSM for an accurate terrain analysis. The generated DSM provides the key data for Compound Topographic Index calculation from terrain derivatives, such as slope, upstream drainage area, and plan curvature. Thorne et al. (1986) introduced the compound topographic index model (CTI) as a measure of stream power to erode soils. CTI considers topographic attributes such as slope, upstream drainage area, and plan curvature as topographic controls in the formation process of ephemeral gullies [5]. The CTI is defined by:

$$CTI = A \times S \times PC \qquad (1)$$

where: A = upstream drainage area, S = slope and PC = plan curvature. The resulting positive CTI values are only were considered as ephemeral gully since negative values are the result of negative plan curvature (ridges). Maps of positive CTI values were generated for the flight heights of 120m, 240m and 360m figure 2.

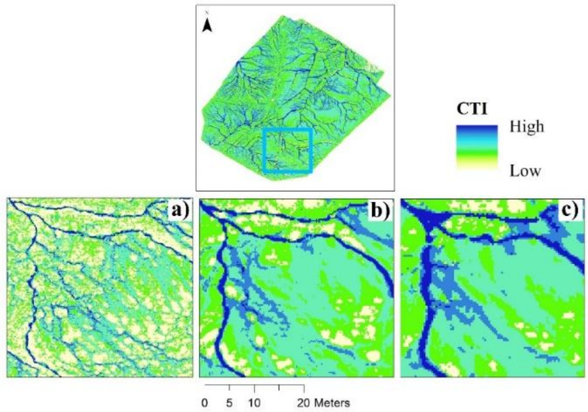

Figure.2*: a) CTI map of flight height 120, b) CTI map of flight height 240, c) CTI map of flight height 360.*

Many studies concluded that DEM resolution substantially affects topographic attributes and thereby model results [7,13,4, 21,16]. In our study the impacts of DSM resolution (10 cm, 20 cm, and 30 cm) on the performance of CTI were evaluated by the delineation of ephemeral gullies in three different scales EG_{120}, EG_{240} and EG_{360} with an output of different percentage of areas (1.2 %, 3.2%,3.8%) The main morphological characteristics of the delineated EG are the length, depth and volume they provide a better understanding of soil volume that can be transported within a channel [19]. From the hydro tools GIS algorithm and from each DSM we calculated flow direction, flow accumulation than streamlines figure 3. These generated streamlines draped on the ephemeral gullies shapes for the EG length calculation. The three levels of DSM are cropped by the EG shapes for the calculation of the depth and volume of each pixel in the raster data format. The spatial resolution of all DSM, the height, depth, and volume are trigonometrically calculated in a raster calculation.

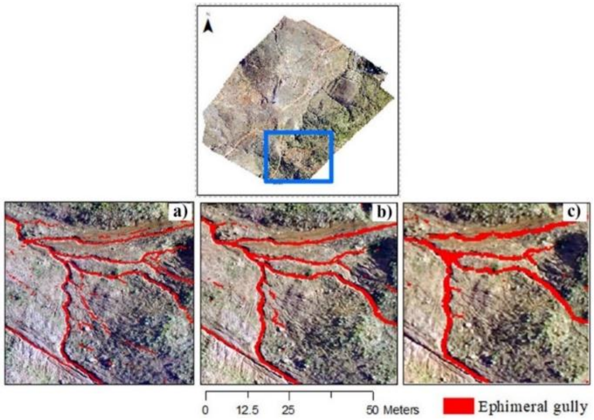

Figure.3: *a) EG map of flight height 120, b) EG map of flight height 240 c) EG map of flight height 360.*

4. Results and discussions

After delineating EG from the positive CTI values, figure 3 shows a scale series of CTI maps highlighting EG in dark colors, the small area of EG_{120} due to the thin channels generated from high spatial resolution figure 3a. With the change of flight height, gully channels became thicker and their areas became bigger as shown in higher flights results: EG_{240} and EG_{360}. To more understand the effect of CTI values with the scale we calculated the statistics of CTI values inside each of the gully shape EG_{120}, EG_{240} and EG_{360} Table 2

Table 2: *CTI statistical values*

	Min.	Max	Mean
EG_{120}	-18.06	7.56	-14.78
EG_{240}	-18.06	7.55	-14.12
EG_{360}	-18.06	7.54	-13.76

Table 2 of statistical CTI values within gully shapes show identical minimum values in all scale and a decrease of maximum values with the decrease of spatial resolution (pixel size). We can understand from the Ephemeral gullies CTI delineation that the thickness of gully channels is decreasing with spatial resolution resulting in a difference in areas and CTI values and influencing on researches results. As mentioned above after EG delineation we calculated the geometrical characteristics (length depth and volume) inside each EG shape. Multiscale ephemeral gullies were classified based on depth (GD). Table 3 describes small, medium and large gullies and is commonly used in manuals on erosion.

Table 3: *Gully classes based on depth*

Gully depth percentage of area			
Interval (m)	GD_{120}	GD_{240}	GD_{360}
0-1	85.72	83.04	80.13
1-2	9.05	12.50	15.31
>2	5.22	4.44	4.55

As per table 3 small gullies occupied more than 80% of the gullies total area, the percentage of the area of medium gullies increased with the flight height otherwise small and large gullies areas are decreased. The results of morphological characteristics statistics of table 4 show the decreasing in pixel quantities with flight heights, then gully length is increasing with the flight height due to the decreasing in spatial resolution of raster data format having gully length as pixel values.

Table 4: *statistics of multiscale Morphological characteristics*

Morph. Charc.	E.G.	Pixel	Mean	Std Dev	Skew.	Kurt.	Max.	75% M.	50% M.	25% M.	Min.
Gully Length (m)	120	118957	0.01	0.023	4.161	22.47	0.235	0.01	0.002	0	0
	240	89664	0.089	0.122	2.618	8.74	0.91	0.12	0.044	0.011	0
	360	47187	0.117	0.151	2.07	4.872	0.967	0.162	0.054	0.015	0
Gully Depth (m)	120	118957	0.302	0.656	2.11	3.12	2.679	0	0	0	0
	240	89664	0.354	0.674	1.786	1.874	2.619	0.341	0	0	0
	360	47187	0.387	0.698	1.584	1.079	2.613	0.507	0	0	0
Gully Volume (sq.m)	120	118957	0.004	0.009	2.11	3.13	0.038	0	0	0	0
	240	89664	0	0	2	2	0	0	0	0	0
	360	47187	0	0	2	1	0	0	0	0	0

At EG_{120} the skewness of gully length values tends to the left with high kurtosis toward the low length EG pixels, otherwise, at EG_{240} and EG_{360} gully length skewness values tend to the right near the pixels of mean length values. The mean gully depth values differ from EG_{120} to EG_{360} in a range of 8 cm influencing approximately in the same order on standard deviation and skewness depth values. Gully volume is calculated in square meters and due to small gully volumes in pixels of low spatial resolution EG_{240} and EG_{360} statistical values are rounded to zero. To solve this issue, we graphically represented gully length and volume values on a Log histogram for EG_{120}, EG_{240} and EG_{360} figure 4, 5 and 6.

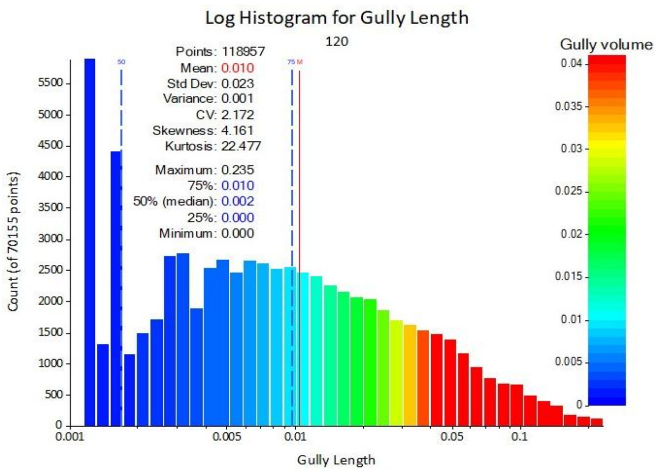

Figure.4: *Log histogram of gully length and volume of the flight height 120*

At EG_{120} 50% of the median goes for the small length gully less than 0.002 m, the 75% median is approximately equal to the mean of gully length value 0.01 m, it means most of the pixels own small length values due to the high spatial resolution. High gully volumes are detected in the pixels of high gully length, maximum gully length of 0.235 m with 0.038 sq. meter. High EG volume begins at 0.04 m EG length.

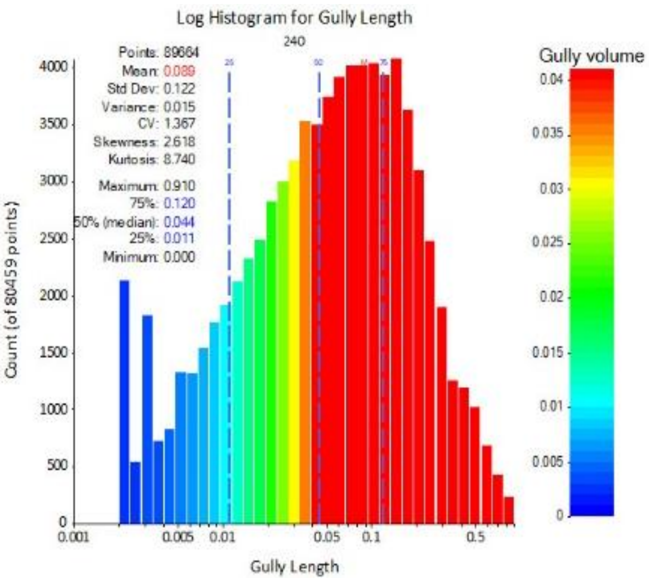

Figure.5: *Log histogram of gully length and volume of the flight height 240 m.*

For EG_{240} the 50% median of gully length between 0.011 and 0.044 m approximately two times bigger than the results of EG_{120}, also the mean value of gully length is 2 times bigger than the 50% median value. High gully volume of 0.04 sq. m are in the interval between 0.04 m and 0.91m of gully length and near the 50% median of the EG length value.

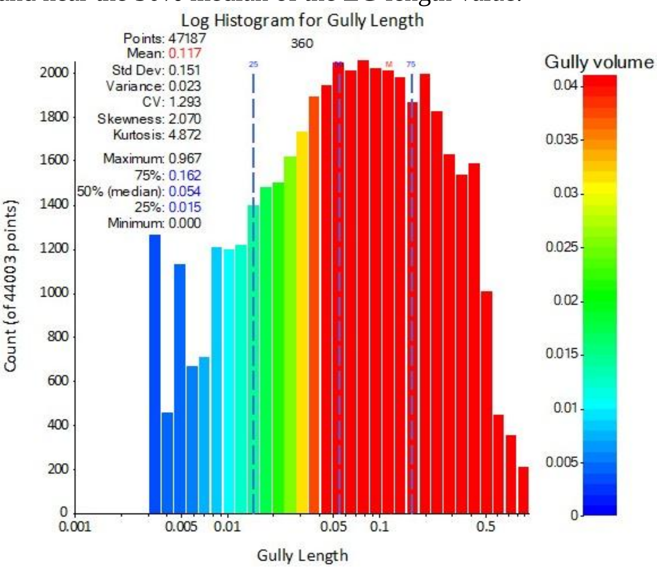

Figure.6: *Log histogram of gully length and volume of the flight height 360*

In the Log histogram of figure 6 of EG_{360} with the low spatial resolution is very similar to the Log histogram of EG_{240} with a small shift in the degree of 0.028 m in EG mean length values between the two datasets. High gully volume of 0.04 sq. m are in the interval between 0.035 m and 0.96m of gully length and near the 50% median of the EG length value. From table 4 and the histograms of figure 4, 5 and 6 we can see that EG_{240} and EG_{360} have very similar values not similar to the values of EG_{120} this is due to the high spatial resolution of the dataset. We can say that there is a scale transition from relief to micro-relief between EG_{240} and EG_{120} and there is a presence of two scales, small scale ephemeral gully expressed by the flight height 240 and 360 m and a much smaller scale in the level of microrelief of the flight height 120 m.

Conclusion

In this study, drone Digital Surface Models (DSM) at different flight heights used as input data with the application of Compound Topographic Index for the delineation of the ephemeral gully at a three flight height 120, 240 and 360. A methodology to apply Thorne and Zevenbergen's (1990) CTI technique within a GIS environment, has been achieved. This is an important step as it demonstrates the potential for incorporating the CTI approach into digital terrain analysis tools of drone-based DSM, which would allow delineation of ephemeral gully channels. In fact, the CTI is a rational equation that predicts the potential for ephemeral gullying on the basis of local values of specific stream power. The results of this paper have clearly demonstrated that the elevation grid resolution having a clear influence over the CTI predictor's performance, this demonstrates a need for more widespread availability of accurate elevation data before the CTI technique can be applied. Also, results show that the effect of cartographic generalization in scales change is very high between flight height 120m an 240m due to the big difference in ephemeral gullies areas. Ephemeral gullies extracted form drone DSM and GIS fast the presented results and discussion by integrating the geospatial multiscale approach. Information and methods discussed in this paper are valuable results for cartographic multiscale studies of ephemeral gullies. Areas and shapes of EG are dissolving with scales against each other's, some of them gaining areas and some disappeared. The morphological characteristics of ephemeral gullies in terms of length, depth and volume, shows a big similarity in values of EG_{240} and EG_{360} and very different than the values of EG_{120}, due to the high spatial resolution. These results highlight the presence of two scales, small scale ephemeral gully expressed by the flight height 240 and 360 m and a much smaller scale in the level of microrelief of the flight height 120 m. Future studies may apply scaling techniques with the inclusion of other factors such as land cover, precipitation, and soil type would likely improve EG model performance and may be useful in simulation of ephemeral gullies.

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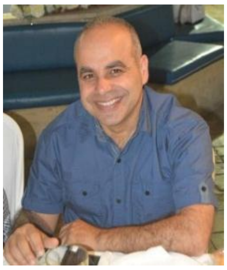

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