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Geomorphometry methods for the classifications and analysis of the isolated hills in Lebanon

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Abstract: Geomorphometry methods for mountain ordering and classifications allow the recognizable proof of precise connections between different morphological parameters. The geomorphometric analysis incorporates quantitative estimation and examination of geography, it explores the impact of help, on landform evolution. Lebanese Mountains are classified based on the hydrological method of Strahlers stream order, closed-loop concentric contour lines define the first-order mountain. Higher-order mountains are defined by a set of closed contour lines containing lower-order mountains and have only one closed contour line for each elevation. This paper generates and classify mountains orders by their circularity forms and test the magnitude of isolated hills dissection, to understand their spatial location and the reason there are. These diverse lithologies and tectonic activities have contributed to developing many types of natural isolated hills of different forms such as circular, oval elongated, and complex shapes. The dissection of these forms of different mountain orders is analyzed by studying the variations in dissection index with mountains order and tested with the geological map of Lebanon. The result shows that the High dissection index value goes to the first and second mountains orders due to high erosion expressed by the high terrain relative relief, and the isolated hills were caused by the orogenic phase which began in the Upper Jurassic during the rise of the two mountainous chains Lebanon and Anti-Lebanon. These isolated hills are mainly part of the Cenomanian of the Cretaceous and the Upper Jurassic formed by the erosion generated from the stream density during this period.

Keywords: Mountains order, dissection index, circularity index

INTRODUCTION

Earth's surface has various relief patterns, any land with elevations higher than its surroundings is called a mountain, their morphology depends on climate and geology; and thus, the geomorphometry of mountains has been conducted in different areas using different methods (Strahler, 1952; Ahnert, 1984; Schmidt and Montgomery, 1995). Digital Elevation Models (DEM) led to high evolution in mountainous terrain analysis (Chase, 1992).

In his paper, James Geikie (1898) classified mountains by accumulation, elevation, and by circumdenudation isolated by erosion. Then Archibald Geikie (1903) classified mountains as volcano mountains, tectonic mountains, outlier mountains, and denudation mountains. In the opinion of Fairbridge, (1968) mountains classification of Archibald Geikie (1903) seems more accurate than the classifications of James Geikie (1898) because it does not contain sub-types and therefore it is clear and easy to use (Fairbridge, 1968).

This paper used geomorphometry methods for the classification of the mountains by Strahler orders, classification by geometric shapes (circularity), and the classification dissection degree.

The most famous hill in the study area is Qornet Es Sawda the highest peak in Lebanon in the Western mountainous chains, hills are not only found in mountainous areas of Lebanon and Anti Lebanon chains but also in plains such as Jabal Terbol in Bekaa valley.

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Geomorphometry is the quantitative terrain analysis using mathematics for the calculation of the shape and dimensions of the earth's surface, shape and has emerged as a powerful tool in morphometric analysis by implementing GIS and remote sensing technologies (Clarke, 1966).

Pike (2000) defined geomorphometry as the quantitative land-surface analysis science. with a new, approach of representing earth topography by the computer manipulation of terrain elevations (Tobler 2000).

Doumit (2017) spoke about the geomorphometry analysis of the Lebanese territory in analytical cartography and GIS. In Lebanon, and several other countries, geographical data are scarce for analysis and studies. this paper involves the integration of open-source DEM in new geomorphometrical methodologies for the extraction and classification of isolated hills to create a database that constitutes a foundation base for both applied and theoretical research.

Lebanese mountainous territory represents special geomorphologic properties, which make it an ideal focus of study and analysis.

Terrain analysis has been sustained by procedure 'discretization' of the terrain surface with the extraction of its elementary parts. All previous geomorphometric studies are based on the Eastern and Western mountainous chains of Lebanon and ignore isolated, unidentified, and unstudied hills. From here came this research by answering the question "where and why are there isolated hills in Lebanon" in a geomorphological way. The generation of closed hills and the study of their spatial location in the geological map of Lebanon and the dissection effect on their various geometrical forms.

By using modern geomorphometry methods applied in Geographic Information Systems (GIS) and Digital Elevation Models (DEM), new horizons were opened up before us that were not available to geographers in the old days. this research will deal with extracting and classifying isolated hills and knowing the extent of the effect of dissection on their various forms.

This research with field and laboratory tests will open doors to many future paleogeography and paleoclimate studies.

RESEARCH DESIGN & METHODS

The study area within the boundary of the Lebanese Republic is in the center of the Eastern coast of the Mediterranean Sea, its northern and eastern limits run alongside Syria and the Galilee closes the loop to the south. From East to West, in its widest part, Lebanon is 85 km and from south to north, its coast stretches over 225 km.

The study area constituted from two mountainous chains, the high plateau of Mount Lebanon and the Libano-Syrian plateau of Anti Lebanon generally figure 1.

Mount-Lebanon extends from the North beginning from the Aakar mountains up to an elevation of 3,080 meters above the sea level at the top of Qornet Es Saouda toward Niha mountain 1,809 meters with a total length of 160 kilometers. The high altitude area of Mount Lebanon is the most diversified, the intermediate graduation between the Mediterranean Sea and the ridge of Mount Lebanon chain is formed by several small hills and cut by parallel narrow valleys, carrying rivers and watercourse.

The Beqaa valley at an average elevation of 900 m, elongated to the South about 120 km with a width of 30 km and a maximum of 2,616 meters above the Sea level at Tallet Moussa. The plateau inclines southward to reach an elevated plain (1,400 m).

The geography of Lebanon is shaped basically of sedimentary carbon rocks, limestone, and dolomite. Jurassic and cretaceous limestone constitutes the majority of the Lebanese territory. Other than sediments inside the plain of Aakkar or the Bekaa valley, these are the center karstic arrangements that determine water assets in Lebanon.

Lebanon soils are youthful, delicate, and subject to erosion, particularly within the mountains and slopes that represents over 73% of the Lebanese terrain, precipitations and surface runoff are major components expanding erosion caused by the precipitations, particularly where the defensive green cover has vanished.

Lebanon's situation at the Mediterranean Sea in the Northern temperate zone and its morphology characterize its climate. The two mountain chains, Mount-Lebanon and Anti-Lebanon, expanding perpendicularly produce climatic variability. Hence, a 50 km cross-section shows climate variations: a subtropical coastal climate than at low elevations a typically Mediterranean climate and at higher elevations cold weather covered with snow during the winter.

Mount-Lebanon shapes a boundary against the rain development and the precipitations can reach over 1400 mm per annum (the larger part of which is snow). As for the Anti-Lebanon, precipitation is around 600 mm and increments up to over 1000 mm in Jabal el Cheikh.

Lebanon has 15 rivers, originating from the Mount-Lebanon mountainous chain, spilling into the Mediterranean Sea, except for the Orontes River flowing to the North towards Syria and the Hasbani flowing to the South.

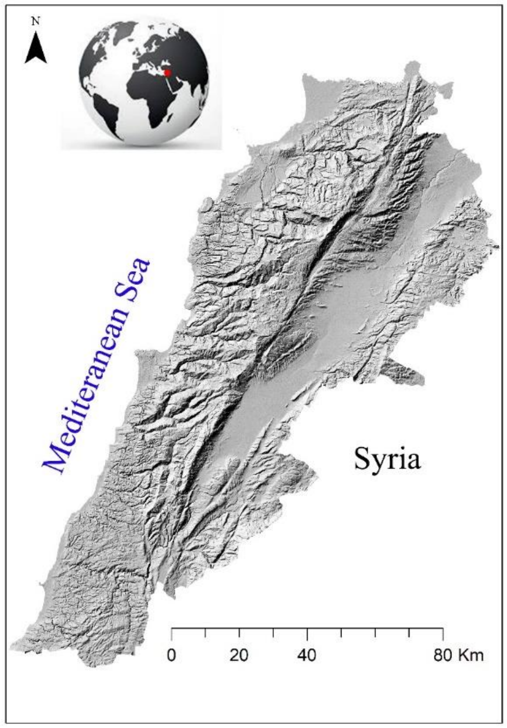

Figure 1. Hillshade map of the study area with terrain texture

Figure 1 of the Lebanese hillshade map showing the valley and mountain terrain structures of the study area. The Digital Elevation Model (DEM) used in this study is the Phased Array Type L-band Synthetic Aperture Radar (PALSAR) of Land Observing Satellite (ALOS) with a high spatial resolution of 12.5 meters, L-band SAR penetrates forest canopy and is used for forest and non-forest mapping (GFOI 2016). We used these datasets which have a reduced to exclude vegetation influences on DEM as far as our study is dealing with terrain analysis.

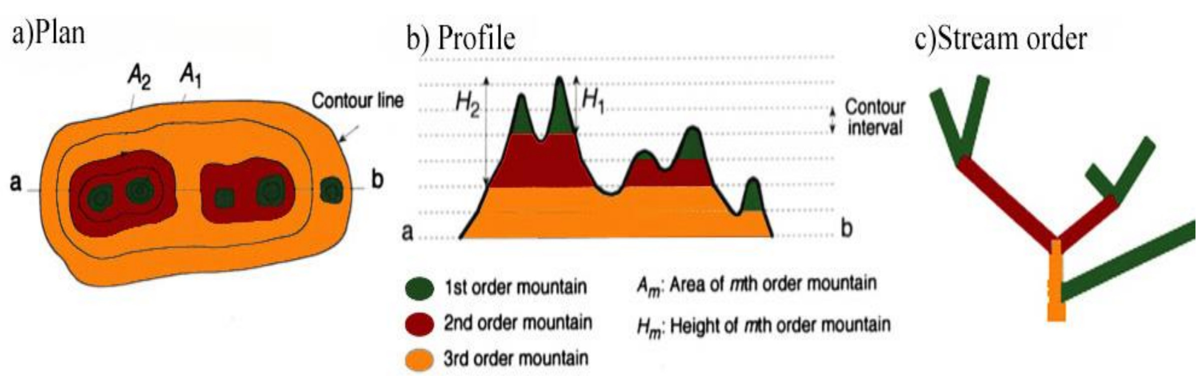

Figure 2. mountains orders sketch a) plan view, b) profile view, c) stream order (After Yamada, 1999).

Figure 2a shows a plan view of the terrain expressed by contour lines and figure 2b the profile ab explaining the mountain orders methodology related to Strahler orders of figure 2c.

Closed contour lines of concentric shapes characterize first-order mountains, these sets of contours incorporate a single contour line for each height unless a col that isolates the mountain's height surpasses the contour lines interval figure 2b.

Higher-order mountains are characterized by a set of closed contour lines containing contours for one or more lower-order mountains and with only one closed contour for each elevation. If the highest enclosed lower-order mountains are of level m, then the surrounding higher-order mountain is identified as an m+1th-order mountain.

The proposed definition for mountain order is similar to the Strahler stream order (Strahler 1952) (Figure 2). the two first-order mountains can form a second-order mountain, but at a lower elevation another first-order mountain cannot make the second-order into a third-order mountain; only the second-order mountain and another second-order mountain can form a third-order mountain (Yamada, 1999, Mîndrescu,2003).

A well-dissected mountain range is identified as a higher-order mountain, whereas a poorly dissected mountain is identified as a lower-order mountain. A col that divides two higher-order mountains will be deeper than a col that divides the lower-order mountains (Yamada, 1999, Mîndrescu,2003).

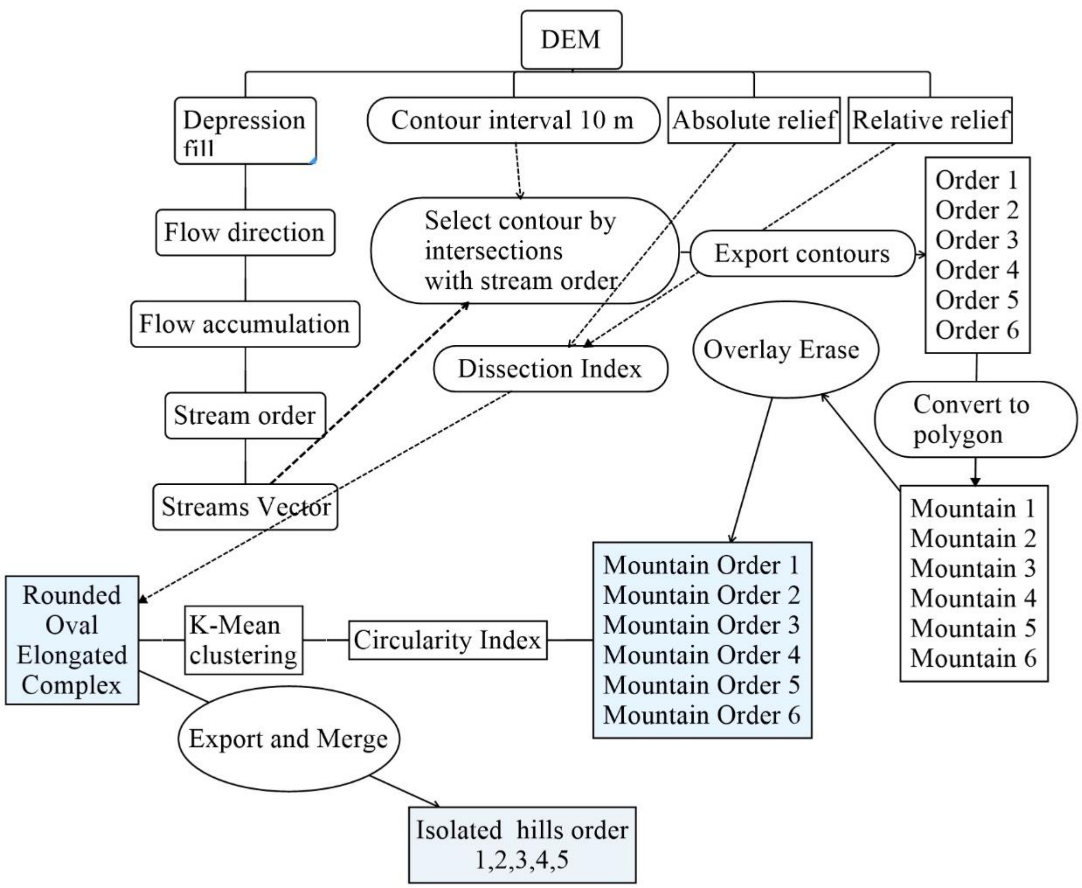

Figure 3. The workflow of the study method.

Digital Elevation Model raster is a discretization of the topographic height values, containing natural depressions such as wetlands, and karst landforms, and artificial sinks caused by noise during data acquisition or by an interpolation technique. These sinks will block the water flow and gives errors in the stream network generation.

Hydrologic correction requires the filling of these sinks, sinks that represent real natural features should not be filled (Jensen & Domingue, 1988).

Sink filling algorithms in GIS software can differentiate between two types of depressions, they treat sinks by lowering the selected DEM elevation values to simulate breaching of the obstruction, or dam, across the drainage path.

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The resultant DEM after a Fill operation is employed in the generation of flow direction, flow accumulation, and streams network. Without filling the sinks, no hydrological project could run properly, which will lead to discontinous braked stream networks.

The fundamental principle behind determining flow direction is that water will flow from a higher place to a lower place. The concept of flow direction is exceptionally imperative since it permits the inference of drainage area, flow lengths, and the watersheds' automated delineation.

Once the depressions and flat areas are treated, the flow directions are determined for each and all. The flow direction is determined by recognizing the neighboring cell which has the highest positive distance weighted drop (Jensen & Domingue, 1988).

Basing on flow directions, we determined the flow accumulation, Flow accumulation is very important it determines the size of the region over which water from rainfall, snowfall, etc. can be aggregated. Flow accumulation is computed by accumulating the weight for all cells that flow into each downslope cell (Jenson & Domingue, 1988).

The stream order hierarchy was proposed by Arthur Newell Strahler in 1952 as a first-order stream is the smallest stream and comprises of little tributaries. These are the streams that flow into and 'feed' bigger streams but seldom have any water streaming into them. The first and second-order streams formed one steep slope and flow rapidly until they moderate down and meet the following order conduit.

When examining stream orders, recognize the design related to developing streams up the hierarchy of strength. Since the smallest tributaries are classified as the first order, they at that point take a joining of two first-order streams to create a second-order stream. When two-second order streams combine, they shape a third-order stream, and when two third-order streams connect, they shape a fourth and so on. The first through third-order streams are also called headwater streams and constitute any conduits within the upper comes to of the watershed.

Methods of stream orders are important to geographers, geologists, hydrologists, and other scientists. They allow the study of sediment, and the use of waterways as natural resources and gives an important component to water management. In our study, stream order has been used in geographic information systems (GIS) to map river networks and classify the Lebanese mountains by Strahler order (Doumit 2017).

The mountain ordering workflow of figure 3 begins with vector generations, stream networks, and contour lines of 10 m intervals covering the whole Lebanese territory.

Contour lines intersected with stream vector were exported and converted to form the six mountains orders.

For the classification of the Lebanese mountains by their shapes, the circularity index *CI* introduced by Miller (1953) for watershed basin circulatory calculations was applied in our study for the closed-loop mountains circularity calculations following equation 1:

The Mountain circulatory base area to the area of a circle having a circumference equal to the perimeter of the mountain.

$$CI = \frac{4\pi A}{P^2} \tag{1}$$

Where, *CI* = Circulatory ratio, *A* = Area of a circle having the same length of perimeter as the mountain circulatory base. *P* is the mountain circulatory base perimeter.

Rounded closed-loop mountains have a circularity index close to 1 indicates circularity forms, low circularity index is associated with elongate and complex mountain forms.

Circularity values of the closed hill are heterogeneous to be comparable, they were normalized so maximum circularity value is taken as 1, and other others are changed proportionally. The Normalization is not a mandatory procedure, but it provides a relatively equal contribution of each measure in clustering, regardless of their metrics.

The generated mountains six orders were grouped by their circularity using the K-Means attribute-based clustering plugin of Quantum GIS, the four clusters of circularity index were, rounded (circular), oval, elongated, and very complex forms.

These forms occur over time due to plate tectonics, erosion, volcanism, and weathering, to differentiate physiographic relief characteristics of the four mountains forms we calculated geomorphometric parameters, of Absolute Relief (AR) and Relative Relief (RR) to led to the Dissection Index (DI).

The Relative relief (RR) calculates the difference between the maximum and minimum elevation in a unit area (Isolated hills).

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The Absolute Relief (AR) is a maximum elevation of a unit area (isolated hills), AR is the maximum elevation inside each polygon representing an isolated hill, it is used in determining the erosional characteristics of the isolated hills and it is a function of tectonic processes.

Dissection Index (DI) is the proportion between relative relief and absolute altitude, the areal separation of this ratio will grant the estimation of the vertical erosion balance.
Nir (1957) calculated the 'Dissection Index" as the ratio of two morphometric parameters, relative relief and absolute relief in a unit area. It has been calculated by the following equation:

$$DI = \frac{RR}{AR} \tag{2}$$

DI gives a good value in the estimation of the vertical balance of erosion, DI values vary from 0, a complete absence of dissection to 1 high dissection degree (Doumit and Kiselev 2018).

The rounded hill of all mountains orders was merged in one shapefile to form the rounded isolated hills of Lebanon.

RESULTS & DISCUSSIONS

Based on the applied GIS hydrological algorithm of figure 3, we generated 8 stream orders resulting in the identification of Six-orders mountains in the mountain range, which included approximately 5508 polygons ranging from first-order to 6th order (Figure 4).

The biggest close contour mountain of the 6th order of the Lebanese mountains chain figure 4 yellow color, begins from the North from Qoubaiyat village and end to the south in Kfar Hounin village, with a circumference of 681 kilometers.

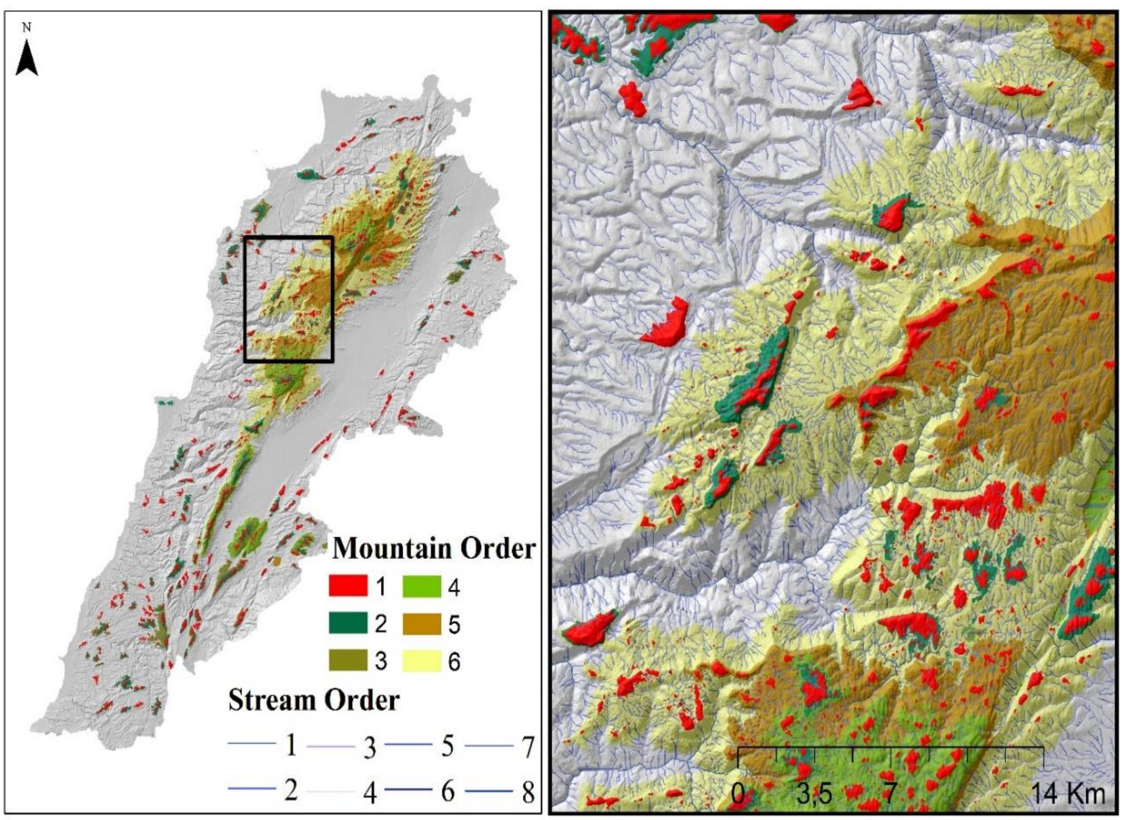

Figure 4. Closed-loop mountains order map.

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The smallest closed-loop contour of the first order mountains with a minimum perimeter of 60 meters was found in Tannourine el Faouqa and Jouret al Akoub in the north of Lebanon.

Figure 4 shows streams and mountain orders from 1 to 6 and highlights well the diverse form of mountain tops and hills.

Table 1

Mountains order numbers, areas, and elevations.

Order	Number	Maximum Area(sq.km)	Minimum Elevation (m)	Maximum Elevation (m)
1	4060	4	45	3080
2	496	15	44	2993
3	272	48	45	2983
4	126	115	226	2833
5	52	397	1056	2574
6	1	1714	1363	1969

Table 1 of the mountain order quantities show a maximum area of 4 square kilometers of the 1st order mountains and the number of 4060 mountain or hill, the number of mountains decrease with the increase in order and area.

The first-order mountain is not only found at Qornet Es Sawda (3080m) the higher elevations point in Lebanon but also at 153 meters above the sea level in the region of Aabbassiyet Sour. The minimum elevation increases with mountain orders and the maximum elevation are decreased with mountain orders, the first order has many mountains small areas and is spatial spread in all the elevation interval between 45 and 3080 meters above the Sea level.

The circularity index of all-mountain orders was calculated from equation number 1 then classified using K-means into four classes rounded, oval, elongated, and complex forms, the first-class belongs to isolated hills types, these isolated 2087 hills with rounded shape constitutes all the mountains tops of Lebanon.

The biggest isolated hill of the first order of 253000 square kilometers in Lebanon is between Ouadi Farra and Maaysret el Hermel villages.

With the Zonal Statistics tool, elevation statistic (minimum, mean, and maximum) was calculated inside each polygon of Isolated hills defined by a zone dataset, based on values from the ALOS DEM dataset for the calculation of dissection index from equation (2). And to more understand how the dissection is influencing these isolated rounded hills we calculated the dissection index of each of the 5 orders in table 2.

Table 2

Isolated mountain orders, numbers, and dissection index values.

Order	Numbers	DI
1	1788	1,47
2	119	1,09
3	129	0,12
4	40	0,06
5	11	0,02

The rounded shapes are detected in all mountains orders except the 6th order and their number decrease with the increase in orders.

High values of Absolute relief was detected in isolated hills of the first order and are a function of tectonic processes and characterized by cold temperature and give the opportunity for snow accumulation, the case of Lebanon Mountains isolated hills.

the increase in absolute relief values leads to an increase in relative relief reflecting a high dynamic potential in the isolated hills.

Dissection Index values quantitatively describe isolated hills geometry to understand their geomorphological structures such as slope, geological and geomorphic history.

DI low values don't offer assistance within the dynamic mobilization of the weathered material, whereas weathered material mobilization is speedy at a lower elevation. A high DI expresses the relation between the relief vertical distance (vertical erosion) and relative relief and expounds the stages of terrain development in the isolated hills.

High dissection index value goes to the first and second orders due to high erosion expressed by the high terrain relative relief.

Besides DI to more understand the geological structures of these isolated hills we compare their spatial positions on the geological map of Dubertret (1953) and we got the results in table 3.

Distributing the isolated hills orders on the geology of Lebanon table 3 shows that the higher percentage of hills number in all orders falls in the Cenomanian limestone and dolomitic limestone type. The isolated hills in the Upper Jurassic dolomite and dolomitic limestone are detected in the first, second, third, and fourth mountain orders.

These isolated hills were caused by the orogenic phase which began in the Upper Jurassic during the rise of the two mountainous chains Lebanon and Anti-Lebanon. These isolated hills are mainly part of the Cenomanian of the Cretaceous and the Upper Jurassic formed by the erosion generated from the stream density during this period.

Isolated hills are those parts that have withstood the process of erosion and have witnessed the basic height of the mountain range before the upper Jurassic.

Table 3

The five orders isolated hill quantities in each geology type.

		Percentage of Isolated Hills number in each order				
	Geology	**1**	**2**	**3**	**4**	**5**
bc	Basalt of Cretaceous	1	1	1	3	-
bj	Basalt of Jurassic	1	2	3	-	-
c1	Neocomian barremian (Sandtone, clay)	3	-	7	-	-
c1-2	Neocomian-Aptian	1	-	6	3	-
c2	Aptian (Dolomitic limestone, argillaceous sandstone, marl)	2	1	4	3	-
c3	Albian (Marly limestone, marl)	5	5	8	-	-
c4	Cenomanian (Limestone, dolomitic limestone)	57	75	49	73	100
c6	Senonian (Chalky marl)	1	1	-	-	-
e	Eocene (limestone chalky limestone)	4	-	1	-	-
j4-7	Upper Jurrasic (Dolomite and dolomitic limestone)	16	11	17	18	-
m2	Miocene (Limestone, sandstone)	1	-	-	-	-
ncg	Miocene and Pliocene (Torrential poundingues)	1	-	-	-	-
qcq b	Scree	2	2	1	-	-
qd	Landslide deposits	-	3	1	-	-
qta	Arable lands	4	-	-	3	-

CONCLUSION

The method of mountain ordering and classification by circularity index can describe the morphology of mountains by the generation of isolated hills. The relationships between mountain order and various morphological parameters such as absolute relief and relative relief, express the magnitude of the mountain's dissection. The results of the mountains ordering technique appear to describe adequately certain basic geomorphometric characteristics.

The diversity in the topography, geology, and Quaternary sediments, has developed different types of isolated hills of different shapes, sizes, and types with the contribution of the weathering and erosion processes. Sheet erosion is hardly effective in anticline geological structures keeping isolated hills of different shapes and sizes. The main reason for developing the isolated hill is the differential weathering and erosion, wind, and water.

The classification of isolated rounded hills by their circularity highlights 2087 hills in the Lebanese terrain of different orders and geological structures. Mountain ordering and classifications with the morphological parameters used will be a useful tool for discussing the development of mountains.

High dissection index value goes to the first and second mountains orders due to high erosion expressed by the high terrain relative relief and different climate factors, these extracted and classified isolated hills are mainly part of the Cenomanian of the Cretaceous and the Upper Jurassic formed by the erosion generated from the stream density during this period.

The result could be a foundation for future tectonic and paleogeography study of the region, the detailed geological structures of these isolated hills of various shapes will be studied to understand the paleoclimate and predict future climate change.

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