Statistical Parameters for Geomorphological Zoning of the Lebanese Orography

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Abstract

Generally, the terrain is characterized by its morphology in terms of similarity and homogeneity, and there are many methods of dividing the terrain into homogeneous zones.

This research came to classify the Lebanese terrain into homogeneous zones by statistical methods based on digital elevation models and for the validation of these geomorphological zones. The resulted map was compared to the geomorphometry and floor vegetation maps of Lebanon after updating them based on the models of digital elevations.

The old geomorphometry and vegetation zoning maps of Lebanon were made from topographic maps digitized and updated based on digital elevation models and GIS geoprocessing algorithms to form a validation platform for the resulted geomorphological zoning map.

A climatological interpretation of each of the generated geomorphological zone could help more in the understanding of the Lebanese orography.

Keywords: DEM, Geomorphometry, Standard deviation, Skewness, and Kurtosis.

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Introduction

The alternative to a linear boundary is a transition zone (strip) obtained by classification of similar values of an indicator. In geomorphology the most informative and simple terrain characteristics indicator is the Digital Elevation Model (DEM).

The hypsometry is the main indicator of transition zones for terrain, and it constitutes an important parameter of the orography.

According to this study, some statistical calculations based on DEM were applied to the territories of Lebanon characterized by the distinguished physical geographical principles, Lebanon mountainous chains, and Beqaa valley which will make it possible to analyze morphologically homogeneous zones and streamlining ideas about their spatial diversity. Another thing is methodologically important: such zoning contributes to the achievement of the relative isomorphism of terrain models.

We can understand by zoning the allocation of areas that have a homogeneous geometrical or morphological characteristics. This often comes down to applying a quantitative indicator that integrally reflects the properties of the earth's surface.

Implementing the Geographic Information System (GIS) in a geometric approach for terrain description gives new possibilities of statistical terrain characteristics calculation.

Several European research use statistical parameters in terrain analysis (Pike & Wilson, 1971; Evans, 1998; Guth, 2006, Guth 2009) and in Russian geography schools (Tregub & Zhavoronkin, 2000; Pogorelov & Doumit, 2009). These works have their preferences in implementing the geometric approach.

Wombling method examines the gradient of the surface around each cell of a DEM and identified boundaries based on the rate of change of a linear surface fitted through the neighborhood of the central cell, with high rates of change being the most significant (Womble, 1951).

A more sophisticated approach is the confusion index, which computes the ratio of the second-highest membership value of a DEM cell and detects areas of high confusion, and then analyzes the transition width (Hengl & Reuter, 2008).

Pogorelov et al. (2017) use the kurtosis values of Digital Elevation Models to delineate Caucasus mountain zones by their morphological criteria. Unfortunately, terrain statistical modeling applications on the Lebanese territories are very weak especially with the applications of Geospatial methods. De Vaumas (1954) based on big scales topographic maps delineate the Lebanese territory using morphometrical parameters (De Vaumas, 1954). Abi Saleh and Safi (1988) made the vegetation map of Lebanon at a scale of 1/500000 based on the terrain elevation intervals (Abi Saleh & Safi, 1988) with the appearance of high spatial resolution Digital Elevation Models (DEM) and the availability of open-source Quantum GIS software and the need for an updated geomorphological zoning map of Lebanon.

This paper tests statistical methods for geomorphological zoning of the Lebanese orography and validates them with morphometrical and vegetation maps in a detailed climatological assessment.

1. Materials and Methods

Morphologically homogeneous zones of a mountainous country like Lebanon could be distinguished by mapping the spatially distributed statistical characteristics of the relief: Standard Deviation, Skewness, and kurtosis.

The DEM used in this project is the Phased Array Type L-band Synthetic Aperture Radar (PALSAR) from the Advanced Land Observing Satellite (ALOS). ALOS offers a suite of terrain corrected data products free of charge at the Alaska Satellite Facility website. These datasets come with a good spatial of 12.5 m for morphometry analysis (Logan et al., 2014).

ALOS DEM processed in QGIS by calculating elevation statistics values (minimum and maximum) inside an elementary squares grid of 50 x 50 meters then interpolate their values to form two raster files of minimum and maximum elevation.

Both raster files are integrated into the Grass software module for the calculation of Standard deviation, Skewness, and Kurtosis of the elevations.

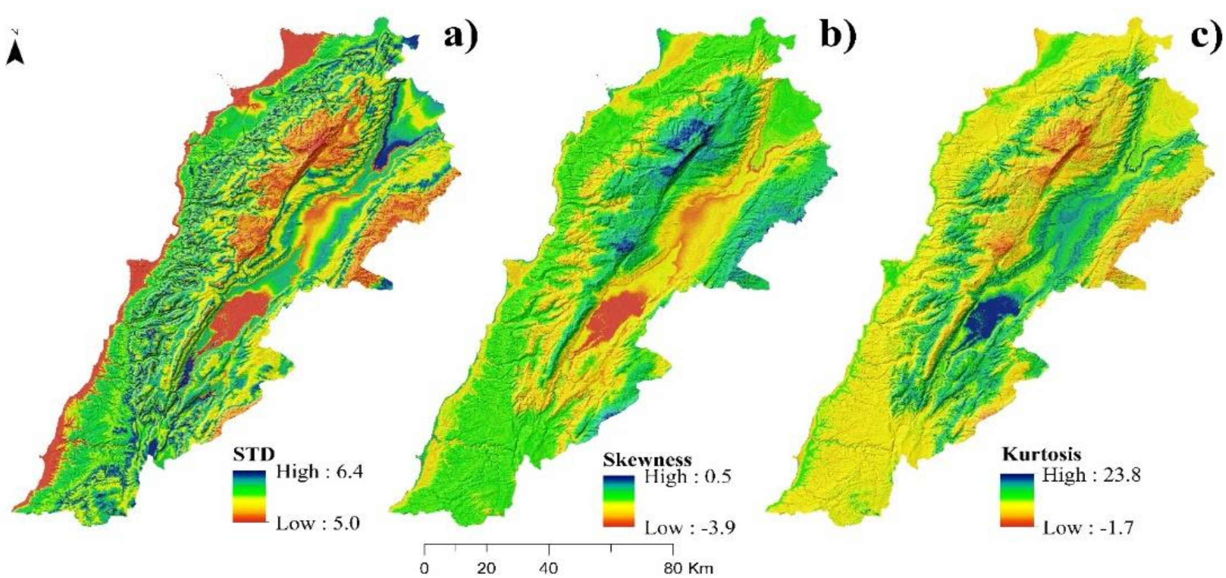

Fig.1: Spatial distribution of elevations statistical values of the Lebanese orography a) Standard deviation of elevations, b) Skewness of elevations, c) kurtosis of elevations.

De Vaumas (1954) described the morphometrical zones of the Lebanese orography (table 1) and used the coefficients of massiveness and aerations to draw the morphometrical zoning map of Lebanon (De Vaumas 1954).

In GIS, De Vaumas morphometric zones were improved and updated based on DEM and the descriptions are shown in Table 1.

Table 1: Descriptions of De Vaumas delineation method for morphometric zoning of Lebanon

Number	Name	Delineation method
1	Northern Lebanon (mountain)	Limit of the lowlands (see 3), the trace of the Syrian Lebanese divide line, the watershed between the Beirut river and Damour river or Jerbane valley.
2	Lebanese foothills	Trace of the Syrian Lebanese fracture, line of contact with the Beqaa plain
3	Northern Lebanon (low country)	Line of contact with the coastal plain (corresponding to the 100 m contour lines), the limit of the basalt outcrops of Akkar, around the Lebanese vault, passing approximately through Qoubayat, Bezbina, khraube, Azqa, Kousba, El Majdel, Meifouk, Joula, El Hessoun, and Ghazir.
4	Southern Lebanon (mountains)	Line of contact with the coastal plain (contour line of 100 m above the sea level), the trace of the large western fold.
5	Southern Lebanon (lowlands)	Line of contact with the coastal plain (contour line of 100 m above the sea level), the stream of Qasmie river, the ridge of Merjayoun anticline, the trace of the large western fold.
6	Lebanese Galilee (high lands)	Streamline of Qasmie river, line of contact with Houle plain, Lebanese-Palestinian border extended to the East until it intersects the previous line, contact with the lowlands (see 7)
7	Lebanese Galilee (lowlands).	Line of contact with the coastal plain (contour line of 100 m above the sea level), streamline of Qasmie river, the trace of Yantar backbend.
8	Bouqeia	The boundary of the plain.
9	Basaltic plateaus of Akkar	Streamline of El Kebir river, southern boundaries of Bouqeia, the trace of the Lebanese Syrian fracture, line of basalts outcrop, contact with the coastal plain (contour line of 100 m above the sea level).
10	Akkar plain and coastal plain	Limit the volcanic plateaus of Akkar and Lebanon (mountain or lowlands) from El Kebir river to Ras Nebi Younes.
11	The coastal plain of Saida	Limit of Lebanon (lowlands) from ras Nebi Younes to the river of Qasmie.
12	Beqaa (Region of Qousseir Laboue)	Line of contact with the front mounts-line drawn from the tip of Akroum to the mount of Hassie and passing not far from Qousseir, contact with Anti-Lebanon, the line drawn where the front mounts and Anti Lebanon come closest (the south of Laboue)
13	Beqaa (Laboue Baalbek region)	Line of contacts with the Anti-Lebanon mountains, transversal lines passing through the narrow lands of Laboue (see 12) and the enlargement areas of Baalbek.
14	Beqaa (Baalbek-Rayak region)	Line of contacts with the front mounts and Anti-Lebanon - transversal lines passing through the umbilicus of Baalbek and the narrow lands of Rayak.
15	Beqaa (region Rayak Joub Jenine)	Trace of the Lebanese Syrian fracture, the trace of the Cenomanian monoclinal depression (Ouadi Teim), transversal lines passing through the narrow lands of Rayak and by the foot of El Gharbi mount (Joub Jenine).
16	El Gharbi mounts.	Trace of the Syrian Lebanese fracture, the trace of Wadi Teim monoclinal depression, transversal lines passing through the foot of El Gharbi mount to the North and by the village of Blate to the South.
17	Merjayoun.	Anticline ridgelines of Merjayoun and El Khiam, the transversal line passing through the village of Blate.
18	Hasbani Syncline	The Ridge of El Khiyam anticline, foot of the Hermon mountain, transversal line East-West passing through the southern point of the Hermon, this line marks roughly the contact of basalt outcrops with the plain of Houle.
19	Djebel hassie.	Line of contacts with the Beqaa and with the Syrian desert, line of talwegs separating Hassie mountain from Anti Lebanon, this line limits the great anticline Halime Talaat Moussa to the north.

20	Anti-Lebanon (northern part)	Line of contact with the Beqaa, the trace of the Eastern back fold, transversal lines passing south of the mountain of Hassie and through Talaat Moussa.
21	Anti-Lebanon (southern part).	Line of contact with the Beqaa, trace of the eastern back fold, transversal lines passing through Talaat Moussa and Chekif mountain.
22	Barada saddle	Trace of the monoclinal depression (Ouadi Teim), transversal lines passing through Chekif and Hermon mountains, to the edge of the Qalamoun (valleys of Mahdi, Abou Salem, Dimas, and Ras et Ain).
23	Hermon.	Trace of the Cenomanian monoclinal depression (Wadi Teim), border of the south mountain to the -West and South-East, the transversal line passing through the mountain at North-East.
24	Qalamoun	Border of anti-Lebanon (see 20, 21, 22), the line passing through Qara, nebek, the road from Nebek to Damascus until it leads to the edge of Qasioun, Qatana mountains.
25	The coastal plain of Tire.	Line of contact with the lowlands of Lebanon and the Galilee (corresponding to the 100 m contour lines), Streamline of Qasmie- Ras el Abiad.

Table 1 shows De Vaumas nominations of 25 morphometric zones of Lebanon with detailed descriptions. Each zone has specific geomorphometric characteristics related to hypsometry, minimum, maximum elevations, coefficient of massiveness, and aerations.

The original map of De Vaumas was made following the descriptions in Table 1. The updated map of De Vaumas based on ALOS DEM in a GIS environment following the descriptions in Table 1 gives an output of new more accurate, precise, and high-resolution morphometric zones map (figure 4b).

The second elevation zoning map or vegetation map, made by Abi Saleh and Safi (1988), classified Lebanese territories into nine classes as shown in Table 2.

Table 2: Abi Saleh and Safi (1988) vegetation map classifications based on terrain elevations

Number	Name	Descriptions
1	Lower Mediterranean floor	It rises from the coast up to an altitude of approximately 500 m, on the western slope of Mount Lebanon. The limit of this stage passes appreciably from North to South, through these localities Helba, Amioun, Ghazir, Jamhour, and Nabatiyé.
2	Eu Mediterranean floor	The altitudinal limits of this floor are between approximately 500 and 1000 m on the western reverse of Mount Lebanon. Its upper limit rises a little more in the southern part of the Eastern reverse of the same chain and the Hermon. This limit passes from North to South through these localities: around Sir ed Denniyé, Qartaba, Rayfoun, Bikfaya, Bhamdoun, Kfar Nabrach, Jezzine. It goes around Mount Lebanon by Machghara, Khirbet, Qanafar up to the level of Zahlé. On Anti-Lebanon, the limit passes at the feet of Majdel Aanjar, Jib Jannine, and Hasbaya.
3	Supra Mediterranean floor	The altitudinal limits of this floor are between 1000 and 1500-1600 m approximately on the western slopes of Mount Lebanon and Hermon and on part of the eastern slope south of the parallel of Beirut.
4	Mediterranean mountains floor	The altitudinal limits of this floor vary between 1500 m and 1800 m approximately.
5	Oro Mediterranean floor	The lower limit of this floor is around 2000 m to reach the highest peaks of Mount Lebanon by overflowing a little on the eastern slope. This floor is differentiated only in the northern part of the country because at this level Mount Lebanon peaks at 2088 m.
6	Pre-steppe Mediterranean floor	The altitudinal limits of this level are between 900 and 1,400 m approximately on the eastern slope of Mount Lebanon and between 1,000 and 1,500 m on the western facade of North Anti-Lebanon.
7	Pre-steppe Supra Mediterranean floor	The altitudinal limits of this floor vary between 1,400 - 1,500 m and approximately 1,700 - 1,800 m on the eastern facade of Mont-Lebanon. These limits are slightly offset on the west facade of Anti-Lebanon.

8	Pre-steppe Mediterranean mountains floor	This floor is between 1800 and 2300-2400 m on the eastern slope of Mount Lebanon.
9	Pre-steppe Oro Mediterranean floor	It is from around 2400 m, the lower limit of the Pre steppe Oro Mediterranean stage is on the eastern facade of Mount Lebanon.

The vegetation floor map of Abi Saleh and Safi (1988) was drawn based on topographic maps at a scale of 1/500000. In GIS the interpretation of the vegetation floors description of Table 2 allowed the generation of a new detailed digital vegetation map of Lebanon (figure 4c).

Results and discussions

The standard deviation map of elevation generated from ALOS DEM (Figure 1a) characterizes the elevation scattering relative to the average elevation in the elementary square. Without going into a detailed analysis of the map, the standard deviation of elevation is considered the most complete, clear, and compact indicator of terrain dissection or relief energy, reflecting the intensity of the terrain formation processes (Pogorelov & Netrebin, 2011).

Low standard deviations values (see Figure 1a) are found in plain areas (coastal plain and Beqaa wetlands). The skewness map of elevation distribution has no analogs in traditional morphometry. Its interpretation allows revealing the dynamics of terrain morphogenesis by the ratio of prevailing and elevation average (Pogorelov & Netrebin, 2011). Positive skewness values indicate the predominance of higher elevations in the topography of Figure 1b at Sannine and Qornet Es Sawda mountains. Negative asymmetry values, on the contrary, indicate a decrease in vertical dissection, such relationships are found in plain areas of Beqaa wetlands.

Kurtosis is a measure that describes the shape of a distribution's tails about its overall shape. It is the measures of “tailedness,” not “peakedness”. The singularity of the kurtosis elevation map result could not be compared with any other morphometric parameter.

The normal distribution has kurtosis = 0 (mesokurtic) distribution with a positive kurtosis and has a high pointed peak (leptokurtic), and distribution with a negative kurtosis which has a flat top (platykurtic).

The values of kurtosis depend on the morphological complexity of the relief (Tregub & Zhavoronkin, 2000). When the Kurtosis value is 0 (mesokurtic), a stable equilibrium of the relief-forming factors is observed; negative values (platykurtic) indicate an upward development of the relief figure 1c high kurtosis values are on the top of the Lebanese mountains covering Sannine and Qornet Es Sawda, and positive values (leptokurtic) indicate a downward development of the relief with very similar values of elevations the case of figure 1c the wetland of Beqaa.

According to Pogorelov & Netrebin (2011), the kurtosis elevation map reflects the homogeneity of the relief and it makes it possible to distinguish homogeneous regions with similar morphological properties and origin.

For the identification of morphologically homogeneous territories of Lebanon, we used the kurtosis elevation coefficient values of figure 1c.

The obtained range of the kurtosis values (-1.7 ... 23.8) and the nature of their distribution within the borders of the Lebanese boundaries (Figure 1c) gives the impression of zoning highlighted by different colors in the kurtosis map. To better delineate these zones, the geometric intervals classification method was applied and the whole set was divided into six classes, which served as the basis for subsequent zoning figure 2.

Six regions have been identified, and as seen, they have a regular arrangement associated with the morphological complexity of the earth's surface.

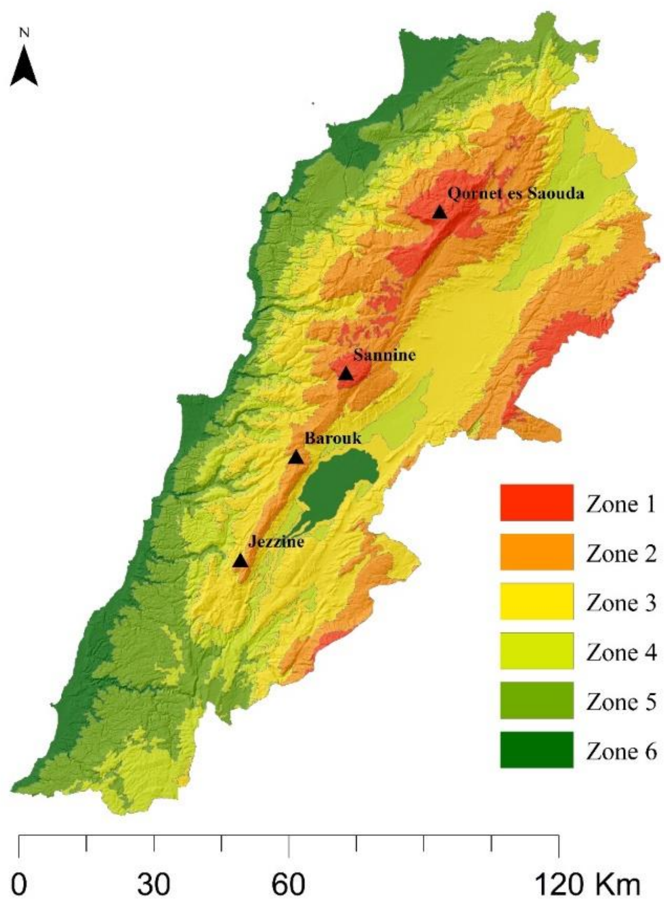

Fig.2. Morphological homogeneous zoning of Lebanese orography.

Figure 2 of the morphological homogeneous six zones of Lebanese orography, zone 1 higher mountainous area englobing Qornet Es Sawda and Sannine it ranges between 1787 to 3097 meter above the sea level and occupied 5.6% from the whole Lebanese territory. Table 3 shows the statistical elevation values within each of the six geomorphological zones.

Table 3: Main characteristics of morphologically homogeneous zones

		Elevation			Standard Deviation			Skewness			Kurtosis		
	Area %	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Zone 1	5.6	1787.4	3097.4	2307.7	1.2	5.9	5.3	-2.2	0.4	-1.1	-1.2	22.1	2.2
Zone 2	19.6	1235.3	2324.0	1722.0	5.1	6.5	5.7	-2.4	-0.8	-1.4	0.8	22.1	4.7
Zone 3	28.7	450.2	1694.3	1120.4	4.2	6.7	5.9	-3.9	-1.2	-2.1	2.4	23.9	10.4
Zone 4	17.0	289.5	1701.4	751.5	4.2	6.7	6.0	-3.9	-1.2	-1.8	2.4	23.9	6.6
Zone 5	18.8	101.3	736.3	382.9	5.1	6.5	6.0	-2.3	-1.4	-1.7	3.1	11.5	4.9
Zone 6	10.3	0.0	905.6	213.5	0.0	6.6	4.0	-3.9	0.6	-2.2	-1.7	23.9	8.5

Zone 2 is very similar to zone 1 where both are related to the mountainous geomorphological part. Zones 3, 4, and 5 constitute the lower, middle, and higher transition zones between coastal and mountainous zones. On the other hand, Zone 6 of the coastal plain and Beqaa wetlands ranges from 0 to 905 meters above sea level. High elevations in this interval are the wetlands ones.

The areas of the districts are generally comparable, except zone 1 (Lebanese Mountains) and zone 6 (plains).

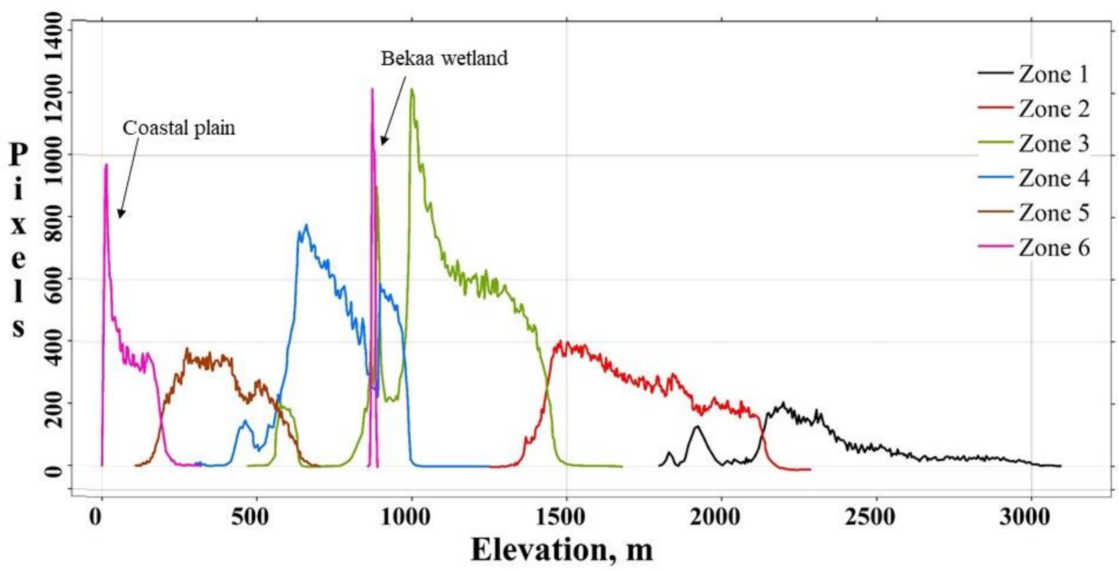

Fig.3. Elevation's histogram of morphological homogenous zones

The histogram of figure 3 reflecting the distribution of heights in the delineated zones allows us to evaluate the territorial variability of the elevations, to comprehend the laws of its distribution from the position of the morphological diversity of the earth's surface. It is seen that each zone is characterized by the elevations above the sea level and the number of pixels related to each elevation interval.

All the zones have continued histograms except zone 6 the histogram is cut at the end of the coastal plain, and it continues at the beginning of the Beqaa wetland and forming a transitional part containing zone 4,3, and 2. Figure 4a.

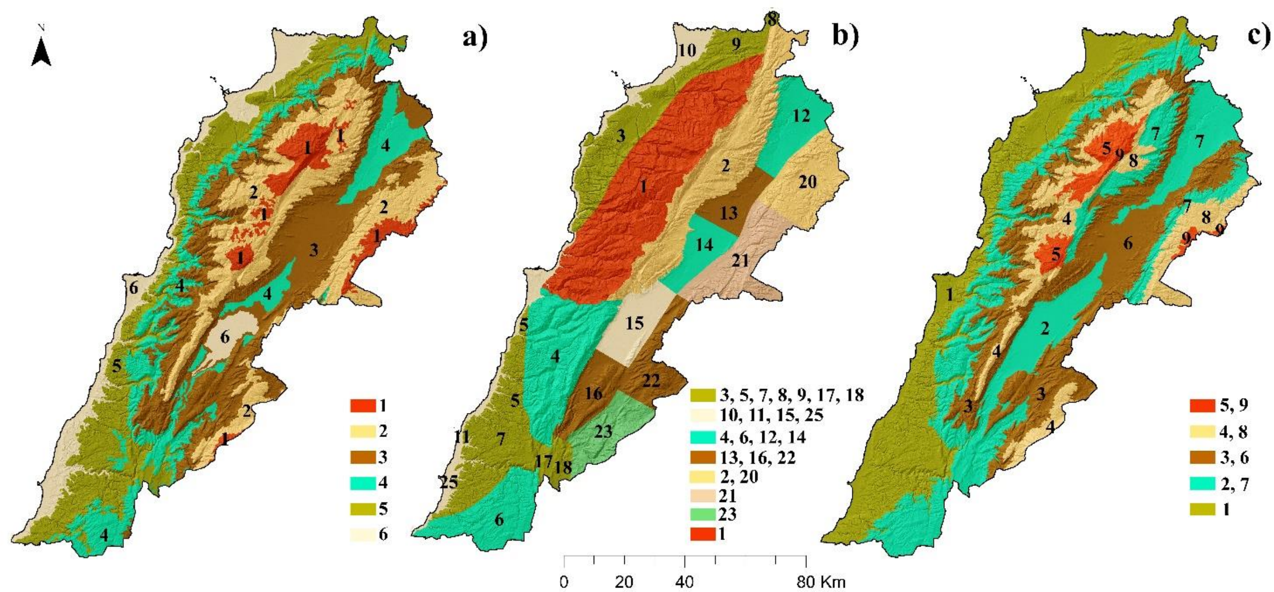

Fig.4. Zoning maps of Lebanon, a) morphological zoning map based on kurtosis elevation values, b) De Vaumas morphometrical zoning map, c) Abi Saleh and Safi vegetation map zoning.

Instead of comparing the resulted map of figure 4a with elevation datasets (DEM, contour lines, elevations) and checking its validity and suitability with other geographic parameters related to the orography, we updated De Vaumas geomorphometric zoning map and the vegetation floors map of Lebanon based on the DEM and the information in table 1 and Table 2, Figure 4b, 4c for the validation of the statistical geomorphological zoning map of Figure 4a.

All classes and legends of the maps of figure 4 were arranged into similar colors and spatial distributions to facilitate the visual analysis.

Zone 6 in figure 4a englobes the coastal plain of Lebanon and the flat wetland of Beqaa and take the same spatial distribution of figure 4b expressed by De Vaumas as zones 10,11,15 and 25 with detailed descriptions in table 1.

Zone 5 of the Kurtosis Morphological Zoning map ranging from 100 to 736 meters above the sea level is approximately the same in figure 4 b and figure 4c of the vegetation map with a merge of zones 6 and 5 of the kurtosis morphological zoning map.

Zone 4 in both maps of figures 4a and 4c constitute a belt around the mount of Lebanon. As for figure 4b zones 4 and 1 are not suitable to the classification of figure 4a and 4c.

Zone 3 of figure 4a is for the Beqaa valley ranging from 450 to 1694 meters above the sea level and match zone 3 and 6 of figure 4c.

The mountainous belt of zone 2 matches and figure 4c of the vegetation floors are described in Table 2 under zones 4 and 8.

The high mountains of Lebanon (Qornet Es Sawda and Sannine) are classified as zone 1 in the kurtosis morphological zoning map and with the same spatial distribution. They are in the vegetation map under zone 5 and 9.

Because of the statistical morphological zoning of the Lebanese orography, the map of figure 4a matches the map of De Vaumas in all classes except the area of Mount Lebanon and match the vegetation floors map of Lebanon because the maps of figure 4a and 4c are based on the orography. Also half of De Vaumas geomorphometric map is delineated from contour lines (Table 1) which means from the same origin and source (The Orography of Lebanon).

The result proves that the Kurtosis distribution of elevations is very suitable for morphological zoning and saves the elevation values for morphological homogeneous zones.

The six zones differ significantly in morphometric indicators, and these changes find their physical explanation in a small climatological interpretation. The precipitation data are downloaded on a monthly and yearly time basis from the three sources of NOAA (National Oceanic and Atmospheric Administration) and the TRMM (Tropical Rainfall Measuring Mission) and CHRS (Center for Hydrometeorology and Remote Sensing) data. The data were validated from fixed weather stations such as the one at Beirut International Airport.

The data are grouped according to different altitudes respecting the 6 classified morphological zones. the results obtained show a strong correlation between the morphological zones and the zones representing the distribution of precipitations strongly related to the latitude and the altitude and the complex topography of Lebanon.

If we associate the 6 generated morphological zones with the precipitation distribution, we can distinguish two essential parts one under masses effect of very humid air coming from the

Mediterranean Sea receiving around 900 mm per year on the coastal zone 6, raising to 1,800 mm at the mountain peaks of zone 1 in Figure 4a, the second part "under the wind" sheltered by the mountain range drawn up parallel to the coast. Therefore, rainfall decreases rapidly as one goes East and North-East. By crossing the mountain barrier, the winds lose a large part of their humidity, the air compresses in its downward movement and heats up, so it dries up (fohn effect): less than 200 mm is recorded in North Beqaa of zone 4, where the shelter effect has particularly accentuated the East of the highest points of zone 1.

The coastal zone generally receives between 700 to 800 mm of rain per year. This quantity increases to exceed 1000 mm North of Beirut, a region in front of the mountain range of zones 1 and 2 of figure 4a. The Northern part of the coastal zone 6 precisely Akkar plain is noticeably less watered (700 mm).

On Mount Lebanon range of zones 1, 2, and 3, the precipitation increases rapidly with altitude, especially on the massif overlooking the Sea North of Beirut. All zone 1 the top parts of the Western chain have an annual average of over 1800 mm.

In the Southern part, when zone 5 becomes wide, the average precipitation is low, with large local differences that appear depending on altitude and exposure (shelter effect). This decrease in rainfall is explained by both the latitude and the less pronounced character of the relief, the average annual rainfall drops to less than 800 mm per year.

Zones 3 and 4 of Beqaa valley are under the wind effects. Air masses lose much of their moisture on the western slopes zone 2 of the Western Range. The Rainfall decreases from South to North. Southern stations generally receive over 700 mm.

The Northern part of Anti-Lebanon in the morphological zones 1 and 2 figure 4a receives between 400 (in the north) and 600 mm (in the south).

Hermon mountain of zone 1 is relatively well-watered because of the lower altitude of the western chain which shelters it.

The diversity of annual precipitation quantities proves the right classification of the elevation kurtosis map in the 6 geomorphological zones.

Conclusion

The classification of the Lebanese terrain into homogeneous zones by statistical methods based on digital elevation models and GIS algorithms gives an output to a new accurate geomorphological zoning map.

Morphologically homogeneous zones were distinguished by mapping the spatially distributed terrain characteristics from, Standard Deviation, Skewness, and kurtosis. The generated elevations kurtosis map delineates the Lebanese territory in six morphological zones, validated and compared with the geomorphometry and floor vegetation maps after updating and integrating them in a GIS database.

The climatological interpretation of the generated homogeneous zone proves the right classification of the elevation kurtosis map in 6 geomorphological zones.

It should be noted that terrain statistical morphometric analysis forms the basis of geomorphological zoning, and the homogenous zoning map could be a foundation for new various climatologic, vegetation and forestry studies.

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