CHARACTERIZATION OF GREEK MUNICIPALITIES AND SUB-MUNICIPALITIES ACCORDING TO THEIR TOPOGRAPHIC RELIEF

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ABSTRACT:
Relief characterization of administrative units has been very important to national statistical authorities. It is a basic spatial property upon which numerous other phenomena occur. A recently completed project for the National Statistical Service of Greece, had to deal with the global characterization of the municipalities and sub-municipalities (local departments) of the entire Greek territory, into mountainous, semi-mountainous or plane (flat) terrain (M/S/P) according to their topographic relief characteristics. Contrary to the limitations of manual/visual characterizations of the past, this digital procedure is based on a single, explicit, quantified, objective and controllable approach. It involves analysis of morphological characteristics of the entire country, using an appropriate digital terrain model where the main relief parameters affecting the resulting characterization were elevation and slope. Instead of just calculating a final, global characterization (M/S/P) for each municipality or local department, the methodology provides important and very useful individual, internal relief information for each area. The results are presented with series of 2D and 3D relief-type maps, which do not however portray elevation but the weighed characterization relief index expressing "mountainicity". Also, the use of the ternary diagram proves to be very useful in detecting similarities and dissimilarities among the different areas in question.

Keywords: *Relief characterization, Digital Terrain Models, Administrative units, maps.*

1. SCOPE

The objective of the present work is a global characterization and visualization of the municipalities and sub-municipalities (local departments) of the entire Greek territory, into mountainous, semi-mountainous or plane (flat) terrain (M/S/P) according to their topographic relief characteristics. This characterization is included in the general census data for Population, Agriculture, etc. released by the Hellenic National Statistical Services and it often has an impact in funding policies. In the past, characterizations were based on a visual examination of the designated areas against a 1:100,000 scale contour map. The results taken out from this manual procedure, could not be calculated or documented, due to the complex and "fuzzy" criteria employed, the type of data used and the subjectivity of each operator, leading to non-homogeneous accuracy for the resulted characterizations.

On 2002, N.T.U. Athens developed a new digital methodology (presented at the 21st ICC at Durban, South Africa), in order to characterize 1034 new municipalities that came out after merging 5922 old municipalities of the entire Greek territory. In contrary to the limitations of the previous characterizations, this method is based on a single, explicit, quantified, objective and controllable approach. It involves analysis of morphological characteristics of the entire country, using an appropriate digital terrain model where the main relief parameters affecting the resulting characterization were elevation and slope.

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In the present work, this methodology is applied with some important differences:

(a) the calculations were extended to smaller spatial units such as the sub-mucipality level;
(b) the methodology has been refined to account for an analysis at a higher level;
(c) a more detailed (50 m resolution) DTM is utilized;
(d) new relief maps were produced.

2. PRINCIPLES OF THE METHODOLOGY

According to the criteria used in the past for manual characterization, the administrative unit:

- is characterised as **Plane (P)**, if its territory lies in its entirety or in its majority on plane terrain or slightly inclined and with an altitude of less than 800 m from sea level. An existence of a mountain covering up to 1/3 of the area is considered that it does not alter the Plane character of the municipality.

- is characterised as **Semi-Mountainous (S)**, if its territory lies in the foothills, or is approximately divided half in the planes and the other half in mountains, but with an altitude up to 800 m for its greater part.

- is characterised as **Mountainous (M)**, if its terrain surface, in its entirety or in its majority, is very steep, rough, folded, broken up by ridges or covered by mountains, and with an altitude of more than 400 m from sea level. It also includes all areas with an altitude of more than 800 m. An existence of a mountain covering up to 1/3 of the area does not alter the Plane character of the municipality.

Due to the qualitative nature of the lexical terms used in the above definitions, such as "….. is considered that …." or "…. approximately ….", it is inevitable that the definitions present a significant degree of fussiness. Nevertheless, they provide two important and useful semantics, which are taken into account in the digital methodology:

1. The main characterisations are two - **Plane** and **Mountainous**. **Semi-mountainous** is a hybrid situation being half of each. As a corollary, a unit being half Plane and half Semi-mountainous is overall characterised as Plane. Similarly, a unit being half Mountainous and half Semi-mountainous, it is overall characterised as Mountainous. Of course, if it is half Plane and half Mountainous, it is overall characterised as Semi-mountainous.
2. The principle "… in its greater part …" (2/3 that is), implies the following. An area being 2/3 P and 1/3 M is marginally characterised as P, and vice-versa. In addition, if an area is M and P of more than 1/3 each, then it is overall characterised as S.

The basic input for measuring terrain morphology comes from (a) the absolute elevation of surface elements, and (b) their slope. In order to make a productive use of these two measurands for providing a characterisation, the method developed is based on the following principles:

1. Each administrative unit should not be determined with only one single M/S/P/ value, or else a lot of local variability would be lost. Therefore, it is more appropriate to first classify individually small elements (cells) of the surface area. The overall characterisation will result from the statistics of the classified elements.
2. Greater elevations and steeper slopes result into rougher (and therefore mountainous) terrain. Lower elevation and mild slopes imply plane terrain.

3. In larger areas, the characterisation is more generalized, while internal variability is smoothed. If the entire country was to be characterised, that would result into Semi-mountainous.
4. In order to determine the boundary lines for the characterisation, it is necessary to examine the distribution of elevation and slopes though histograms.
5. The classification of terrain should be detailed to provide the opportunity to dynamically fine-tune the overall result.
6. Additional statistical information (min, man and mean elevation and slope) about the global morphology of each administrative unit is important for checking the results.

It must be also noticed, that since the previous characterization, significant changes have been made on the borders of some municipalities.

3. DEM RESOLUTION

The nature of the two basic quantities (elevation and slope) is totally different. Elevation is generally scale-free, since they do not change in a systematic way for data derived from bigger or smaller scale maps. Slope, on the other hand, is scale-dependent, because of its fractal character. Slope increases as reference unit area decreases. It is therefore not very likely that one meets slopes larger than 60% in extended areas, while this is possible in smaller ones. This is another reason why slope/elevation combinations make sense mostly in the characterisation of individual cells and not of entire municipalities.

The cell size (resolution) should be appropriate so that it does not result into excessive detail (variability) or generalisation. It should represent the trend of the relief of the surface, not the local "noise". The analysis of the method and the area characteristics for the characterization made on 2002, showed that a 250m. DEM resolution was appropriate to meet the goal of the project, as the mean municipality area was calculated to 127,4 km^2 and it was covered by 2.038 cells (250x250m^2). Even in extreme cases of the smaller municipalities the number of cells included was adequate.

In the recent work, the resolution of DEM is 100m. (re-sampled to 50m. cell just for better area approximation), because sub-municipalities have clearly smaller polygons. In addition, the distribution of the area of each administrative unit into the combinations of elevation/slope will be more reliable and slope will have an upgraded effect in the final characterization.

4. CLASSIFICATION OF RELIEF

A 4x4 table with 16 combinations of (SL) and elevation (H) was the first approach for the classification of cells, based on the definitions available by the manual characterization method. By analyzing the real slope/elevation values' distribution of the country, as shown in relative histograms of cell values resulted from the DEM (**Fig. 1** and **2**), the table became more detailed and flexible, combining 6 slope and 8 elevation categories which create the final set of 48 combinations (**Fig. 3**). These histograms reveal that the majority of the country's topography, besides any contrary beliefs, has a relatively low elevation and mild slope, i.e., of Plane character.

The same picture is confirmed by the analysis applied on the more detailed DEM of 100m. Some representative examples are the following: 35% of the area of the country has an elevation of less than 200 m, while 22% is lower than 100 m. Above 800 m there is 21% of the country. In addition, 22% of the country has a slope less that 4% and 33% has a slope up to 8%. Above 60% slope presents only 2.9% of the country.

Each of the 48 combinations is subsequently assigned to a class M, S or P. As a result, the following categories are characterized as **Mountainous (M)**:

1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 13, 14, 15, 19, 20, 25, 26, 31

The following categories are characterized as **Semi-Mountainous (S)**:

11, 12, 16, 17, 18, 21, 22, 23, 27, 28, 29, 32, 33, 34, 37, 38, 39, 43, 44, 45

Finally, the following categories are characterized as **Plane (P)**:

24, 30, 35, 36, 40, 41, 42, 46, 47, 48

Based on this table, all cells are classified. Overlaying the polygons of each municipality or sub-municipality with the classified cells, results into the numbers and percentages of cells for the 48 categories. After that, the three (M/S/P) numbers of cells and percentages are produced by summing the proper categories. DEM needs not to be used again, as these percentages are used to compute the final characterization for each spatial unit.

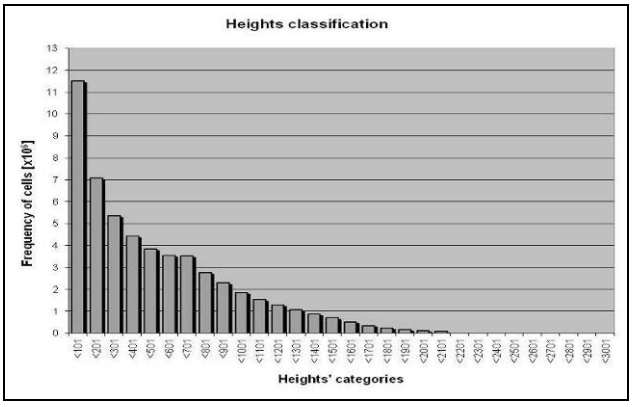

Fig. 1 Height distribution histogram for the entire country. Resolution 100m

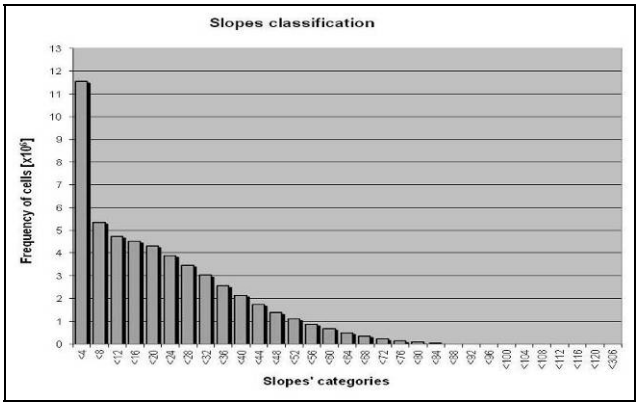

Fig. 2 Slope distribution histogram for the entire country. Resolution 100m

	SL ≥ 60%	60% > SL ≥ 32%	32% > SL ≥ 16%	16% > SL ≥ 8%	8% > SL ≥ 4%	SL < 4%
H ≥ 800m	**1**: 1,74%	**2**: 8,53%	**3**: 7,05%	**4**: 2,60%	**5**: 0,54%	**6**: 0,46%
800 > H ≥ 600	**7**: 0,40%	**8**: 3,06%	**9**: 3,95%	**10**: 2,37%	**11**: 0,76%	**12**: 1,33%
600 > H ≥ 500	**13**: 0,18%	**13**: 0,18%	**15**: 2,42%	**16**: 1,41%	**17**: 0,42%	**18**: 0,58%
500 > H ≥ 400	**19**: 0,17%	**20**: 1,67%	**21**: 2,69%	**22**: 1,66%	**23**: 0,46%	**24**: 0,60%
400 > H ≥ 300	**25**: 0,14%	**26**: 1,60%	**27**: 3,03%	**28**: 2,19%	**29**: 0,66%	**30**: 0,75%
300 > H ≥ 200	**31**: 0,12%	**32**: 1,48%	**33**: 3,29%	**34**: 2,87%	**35**: 1,05%	**36**: 1,31%
200 > H ≥ 100	**37**: 0,11%	**38**: 1,21%	**39**: 3,21%	**40**: 3,55%	**41**: 1,62%	**42**: 3,83%
H < 100m	**43**: 0,05%	**44**: 0,69%	**45**: 2,15%	**46**: 3,19%	**47**: 2,24%	**48**: 12,93%

Fig. 3 The 48 combinations of Slope and Height, area percentages and M/S/P characterization

5. OVERALL CHARACTERIZATION

For an objective overall characterization for each administrative unit, two tools are employed:

1. The computation of a weighed relief index Ri for the terrain, for each unit, based on the 3 percentages of cells in each category (M/S/P).
2. The use of a ternary diagram for positioning each Ri, which subsequently determines the final characterization for the municipality.

The weighted Relief Characterization Index expresses how mountainous an area is, and is computed by the three percentages as follows:

Ri (relief index) = (**10** x **%P**) + (**20** x **%S**) + (**30** x **%M**)

Obviously, 10≤ Ri ≤30. The greater the M percentage, the higher the Ri value and the more mountainous the area. It remains to specify the boundary values, the thresholds for such characterization. Based on the assumptions/principles in the beginning of this section, these boundaries are expressed as follows:

Plane	is defined from	10	to	16.7
Semi-Mountainous	is defined from	16.7	to	23.3
Mountainous	is defined from	23.3	to	30

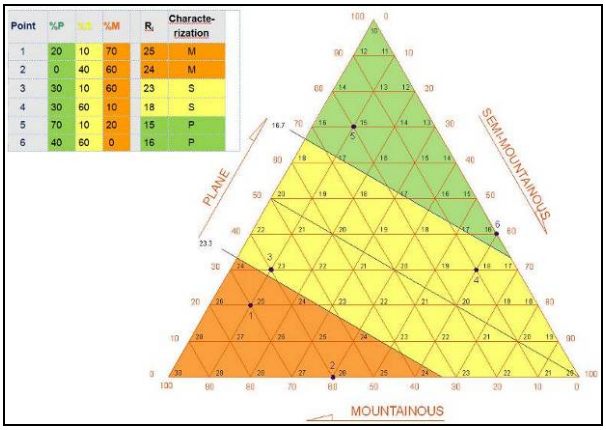

Fig. 4 An example of a ternary diagram with sample points and and M/S/P regions

For the analysis and illustration of three complementary percentages, a very powerful visual tool is the ternary diagram (**Fig. 4**). There are three axes for the %M, %S, %P percentages. Since each unit is expressed by a triplet %M, %S, %P, it can be positioned somewhere in the triangle. The closer the point is placed to a corner, the clearer is the unit's characterization. Some of these cases are shown in the diagram. The thresholds/boundary values expressed before, actually show as straight lines, forming three regions. One bottom left, where Ri mountainous values fall (shown in orange), a middle region (shown in yellow) where Ri semi-mountainous values fall, and thirdly an upper right region (shown in green) where Ri plane values fall. Once the Ri index is computed for each municipality, the latter can be displayed in the ternary space as points, classified as M/S/P.

6. IMPLEMENTATION

The data available for this work were:

- A DEM grid of 100m. resolution for the entire Greek territory
- A geodatabase with the polygons of 1035 municipality and 6130 sub-municipality (total area is 132.168 km^2)

Based on the above principles, the methodology was developed with the following steps:

1. Formation of elevation and slope grid files for the entire territory with a 100 m. resolution and 50m. cell size.

↓

2. Histogram analysis of elevation and slope distributions for the entire territory.

↓

3. Formation of a 48 combination table of 8 elevation-ranges by 6 slope-ranges. Characterization of each one of the 48 combinations into a M/S/P class.

↓

4. Classification of each 100m cell into one of the 48 classes, according to the values of elevation and slope.

↓

5. Overlaying of municipalities and sub-municipalities polygons with the classified grid. Computation of total number of characterized cells in each administrative unit for each of the 48 categories; and subsequently the total percentages of %M, %S, %P of the land of each unit.

↓

6. Computation of elevation ranges, slope ranges, mean elevation and slope, and standard deviations for each unit, used for checking/validation purposes.

↓

7. Computation of the weighted terrain relief index and overall characterization for each municipality and sub-municipality, on the basis of the three percentages %M, %S, %P.

The procedures of terrain data processing (step 1), terrain classification (step 4), overlay of the classified terrain with administrative units (step 5) and statistical processing of elevations and slopes for the units (step 6) were implemented using proper tools from a GIS software (ESRI ArcGIS). Steps (2), (3) and (7) were calculated with a simple spreadsheet software. The ternary plots were produced using specialized software and they were optimized graphically in CorelDraw.

7. RESULTS - CONCLUSIONS

The resulting (actual) area classification for the country is: **mountainous** 38,67%, **semi-mountainous** 30,25% and **plane** 31,08%, where the respective percentages from previous characterization on 2002 (with the 250m. resolution) were 37,87% for mountainous, 30,46% for semi-mountainous and 31,67% of plane terrain.

The final results of the method are the lists with the analytical descriptions of morphology and the final characterizations of all administrative units. A quick, comprehensive picture is given with the percentages of municipalities for each M/S/P category: 29% mountainous, 33% semi-mountainous and 38% of plane terrain, while sub-municipalities are 35% mountainous, 26% semi-mountainous and 39% of plane terrain. An integrated visualization of the M/S/P domain of municipalities and sub-municipalities is given with respective ternary diagrams (**Fig. 5** and **6**), which prove to be very useful in detecting similarities and dissimilarities among the different areas in question.

Map results of the method are shown below. Specifically, **Fig. 6** shows the analytical relief characterization at cell level, **Fig. 7** and **8** show the characterized municipalities and sub-municipalities and **Fig. 9** shows the statistical surfaces of their weighted relief index.

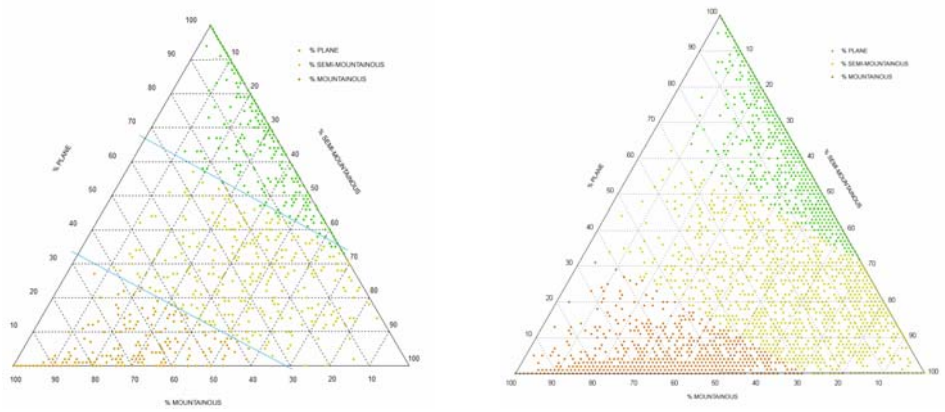

Fig. 5 Spatialization of the 1035 municipalities and 6130 sub-municipalities

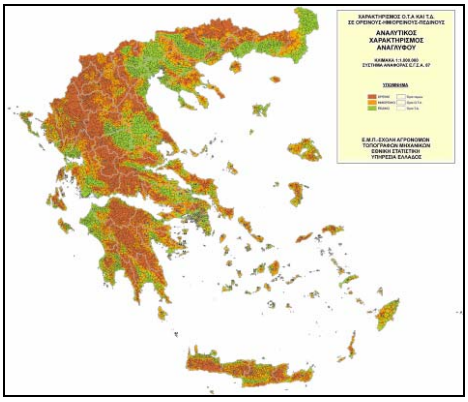

Fig. 6 Analytical relief characterization (M/S/P) at cell level

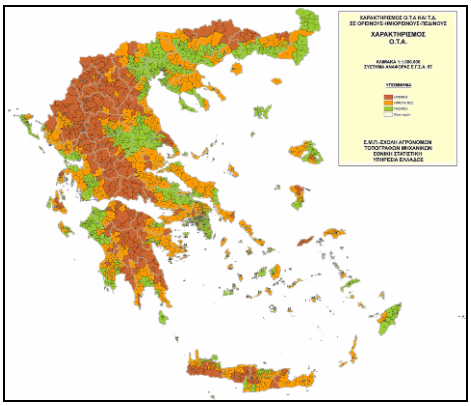

Fig. 7 Characterized municipalities as M/S/P

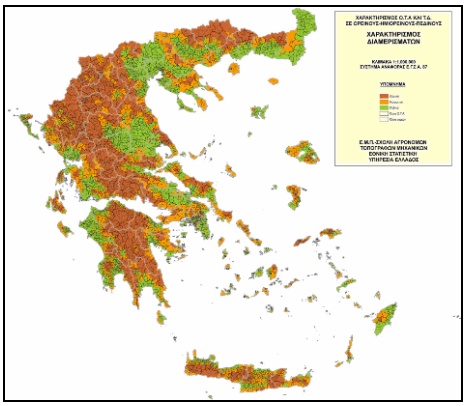

Fig. 8 Characterized sub-municipalities as M/S/P

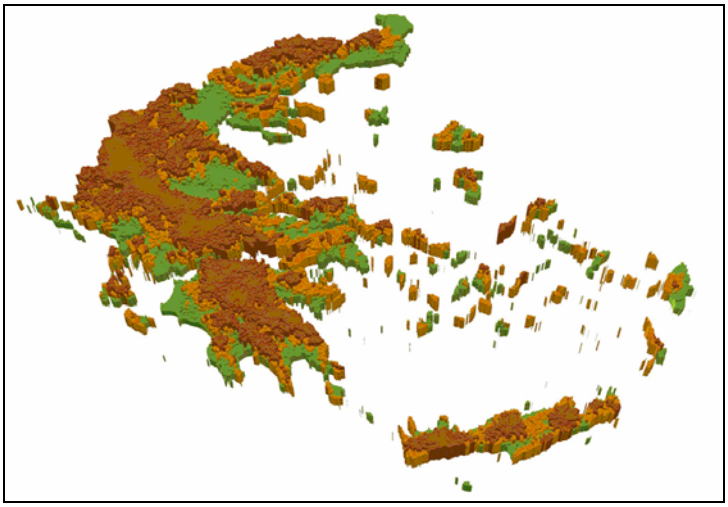

Fig. 9 Statistical surface of weighted relief index of sub-municipalities

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