A RATIONAL CHARACTERIZATION AND VISUALIZATION OF TOPOGRAPHIC RELIEF INTO MOUNTAINOUS, SEMI-MOUNTAINOUS AND PLANE TERRAIN

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ABSTRACT

The objective of the present paper is a rational characterization and visualisation of designated areas (e.g., Municipalities) according to their relief characteristics. Such a global characterisation into Mountainous, Semi-mountainous or Plane Terrain (M/S/P) is often employed by National Statistical Services but depends on several complex morphological criteria. In our case, we did not just conduct an experiment but dealt with the entire Greek territory on behalf of the Hellenic Statistics.

In the past, previous characterizations were based on a manual/visual procedure of examining each municipality area against a 1:100,000 scale contour map. Excluding other "biases", the complex nature of criteria employed then, the subjectivity of each operator and the manual procedure used, lead to non-homogeneous and difficult to document results. The administrative reorganisation of Greece into fewer Municipalities, by a Program known as "Ioannis Kapodistrias" (1991), created the necessity for a new and, this time, more objective and accurate characterisation, exploiting the analytical capabilities available nowadays.

The developed method, contrary to previous limitations, proceeded with a single, explicit, quantified, objective and controllable approach. After analysis of morphological characteristics of the entire country, it was decided to use an appropriate Digital Elevation Model. The main relief parameters affecting the resulting characterization were the Elevation and the Slope.

Instead of a single final single characterization (M/S/P) for each Municipality, the methodology calculates and leads in important and very useful individual internal information for each area. It assigns values into 48 categories (combinations) of slope/elevation, describes ranges of elevations and slope, average elevation and slope, and finally calculates globally individual percentages in three categories M/S/P for each Municipality. Then, using two techniques (a) a weighed characterization relief index, and (b) a ternary diagram, it proceeds with a global characterization M/S/P for each Municipality. The methodology was developed and optimised after being tested in representative regions of Country. Also, comparison with previous characterisations revealed sometimes systematic, other times profound gross "errors". The importance of the characterisation is large considering that funding allocation by the central government is based on such characterisation.

Two visualisation techniques are employed to represent the results of the characterisation. The first is a series of traditional relief-type maps which do not however portray elevation but the weighed characterisation relief index. The second technique is the ternary diagram itself, which is a spatialization method relocating area-points according to their relief characterisation. This second product proves to be very useful in detecting similarities and dissimilarities among the different areas in question.

1. INTRODUCTION

The objective of the present paper is a rational characterization and visualisation of designated areas (e.g., Municipalities) according to their relief characteristics. A global characterisation into Mountainous, Semi-mountainous or Plane Terrain (M/S/P) is often employed by National Statistical Services but depends on several complex morphological criteria. This characterisation is not of mere statistic interest but often has a subsequent impact in funding policies. In our case we did not just conduct an experiment, but dealt with the entire Greek territory on behalf of the Hellenic Statistics.

In the past, previous characterizations were based on a manual/visual procedure of examining each municipality area against a 1:100,000 scale contour map. Excluding other "biases", the complex nature of criteria employed then, the subjectivity of each operator and the manual procedure used, lead to non-homogeneous and difficult to document results. The administrative reorganisation of Greece into fewer Municipalities, by a Program known as “Ioannis Kapodistrias” (1991), created the necessity for a new and, this time, more objective and accurate characterisation, exploiting the analytical capabilities available nowadays.

There is an incredible amount of literature on terrain analysis and classification based on various morphological parameters. Quite of this is already old, but there is also a lot available on the internet. A useful collection has been made by (1). Early quantitative geography techniques (2) addressed some of the issues. More recently, advanced techniques are employed, see for example PhD thesis by J. Wood (3), or work on Relief Classification by (4). The industry has also turned into these applications, see for example the products of “scilands GmbH” concerning "morphographic terrain classification", http://www.scilands.de/e_index.htm . A lot of the work is also directed towards characterizations for specific terrain applications, e.g., avalanche prediction (5), forestry (6), and others. These techniques are very valuable for analysis, but do not always arrive to a rational characterization of immediate practical use, or are domain/application specific. Thus, they could not be used in the present work under the given constraints.

The developed method, contrary to limitations of previous characterizations, proceeds with a single, explicit, quantified, objective and controllable approach. An appropriate Digital Elevation Model is selected after analysis of morphological characteristics of the entire country. The main relief parameters affecting the resulting characterization are Elevation and Slope. The paper is organised as follows. Section 2 describes the available data. Section 3 gives some additional information on the previous characterisation. Section 4 presents the new method. Section 5 outlines the results. Finally, Section 6 evaluates the method and draws some useful conclusions.

2. AVAILABLE DATA

The data available for this work were:

- A DEM of 250 m resolution and (optionally) a DEM of 100 m resolution
- Municipality polygons
- Existing characterisations for the old municipalities

Some useful statistics of the application area are:

- Area of entire Greek territory: 132,024 Km^2
- Number of old municipalities (OM): 5922
- Number of new municipalities (KM) 1034

3. PREVIOUS CHARACTERIZATION - DEFINITIONS

According to the previous characterization, a minicipality:

- 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.

According to these definitions, the characterisation of the old 5922 municipalities was:

- Mountainous (2138 municipalities) 42.3 % of the territory area
- Semi-mountainous (1506 municipalities) 29.0 % of the territory area
- Plane (2278 municipalities) 28.7 % of the territory area

Due to the qualitative nature of the lexical terms used in the above definitions, such as “….. is considered that .”, “. approximately.”, and also some additional terms (area-specific, not included here), it is inevitable that the definitions present a significant degree of fussiness. Nevertheless, they provide some important semantics for the method to be developed. These are:

- The clear characterisations are two - *Plane* and *Mountainous. Semi-mountainous* is a hybrid situation for Municipalities being half of each. As a corollary, a municipality being half Plane and half Semi-mountainous is overall characterised as Plane. Similarly, a municipality 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.

- 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.

4. THE METHOD

4.1 Principles

There are various ways of measuring terrain morphology in order to provide a characterisation (measuring topographic terrain complexity, sinuosity, fractal geometry, etc). Basic input for such a characterisation comes from (a) the absolute elevation of surface elements, and (b) their slope.

The method developed in this research is based on the following principles:

- Greater elevations and steeper slopes result into rougher (and therefore mountainous) terrain. Lower elevation and mild slopes imply plane terrain.
- The characterisation for each municipality should not be determined with the average slope and elevation values, or else a lot of local variability would be lost. This is also true because municipality size varies a lot. 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.
- Elevation is generally scale-free, while slope, because of its fractal character, is not. Slope increases as reference 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 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. The analysis of the method and the area characteristics showed that a DEM with a cell size of 250 m is appropriate to meet the goal of the project. Especially since elevation is more critical in the final characterisation than slope. The use of a DEM with 100 m resolution showed no significant change. A variable size was used for very small municipalities, but mostly for better area approximation and not the characterisation itself.
- The classification should be detailed to provide the opportunity to dynamically fine-tune the overall result. Furthermore, the increased size of the new municipalities makes it necessary to provide internal relief information besides a single M/S/P characterisation.
- In larger areas, the characterisation evens out. If the entire country was to be characterised, that would result into Semi-mountainous.
- In order to determine for the first time the boundary lines for the characterisation, it is necessary to examine the distribution of elevation and slopes though histograms.

Based on the above principles, a method consisting of seven steps was developed.

4.2 Steps

Based on the above realizations and principles, a method was developed with the following steps:

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

↓

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. Classification of each one of the 48 combinations into a M/S/P class.

↓

4. Characterization of each 100m cell into one of the 48 classes.

↓

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

↓

6. Computing elevation ranges, slope ranges, mean elevation and slope, and standard deviations for each municipality. These are used for checking/validation purposes.

↓

7. On the basis of the three percentages %M, %S, %P, a weighted terrain relief index is computed overall single characterization for each municipality is derived based on the use of a weighted terrain index.

Two steps of the method require further explanation. These are:

- Step 3: with the characterization criteria for the individual cells in 48 classes, and
- Step 7: the computation of the weighed terrain index for the municipality and the overall characterization.

4.3 Characterisation criteria

In a first approach, a 4x4 classification table was designed with 16 combinations of Slope (SL) and elevation (H), based on the initial definitions available. This however proved to be over-generalized, for it was not based on the real slope/elevation value distribution of the country. For example, elevation interval 100m<H<600m and slope interval 16%<SL<60%, proved to be very broad. Any attempt to change the classification of a combination resulted to an overcorrection. It was evident that a more rational criteria table was needed. In order to design it, it was necessary to analyze elevation and slope histograms. Here, due to space limitation, only an elevation histogram is shown (Fig. 1). 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. For example, 34% of the area of the country has an elevation of less than 200 m, while 20% is lower than 100 m. Above 800 m there is 21% of the country. In addition, 21% of the country has a slope less that 3%, 33% has a slope up to 7%. Above 60% slope presents only 2.8% of the country.

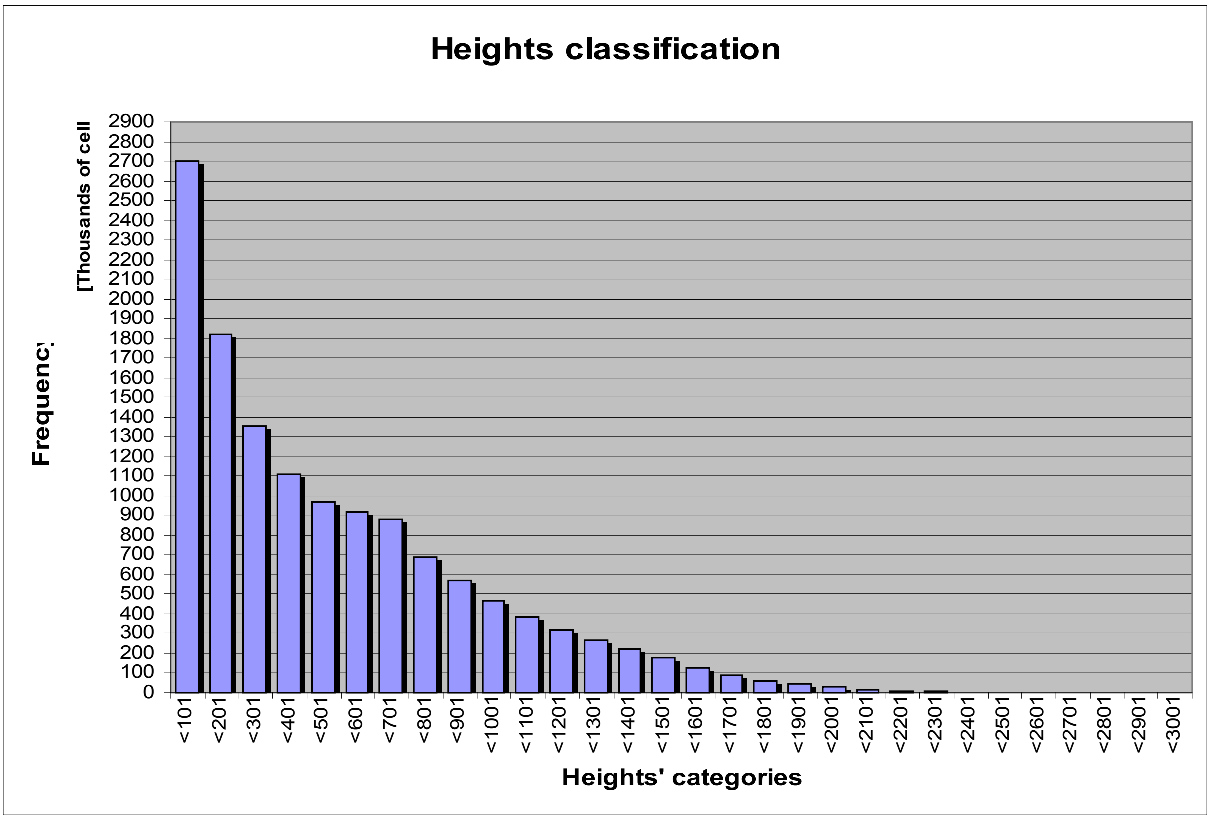

Figure 1. Height distribution histogram for the entire country. Cell size: 100x100 m^2.

Based on these facts, more detailed criteria were formed and a new table was designed (Fig. 2). This allows an optimization of the classification and fine-tuning. The table allows the combination of 6 Slope and 8 Height (elevation) ranges. These result into 48 combinations. Each (of the 1-48) combination contains the percentage of the land area.

	SL ≥ 60%	*60% > SL ≥ 32%*	*32% > SL ≥ 16%*	*16% > SL ≥ 7%*	*7% > SL ≥ 4%*	*SL < 4%*
H ≥ 800m	**1**: 1,65%	**2**: 7,02%	**3**: 7,72%	**4**: 3,57%	**5**: 0,71%	**6**: 0,46%
800 > H ≥ 600	**7**: 0,40%	**8**: 2,47%	**9**: 3,99%	**10**: 2,92%	**11**: 0,97%	**12**: 1,12%
600 > H ≥ 500	**13**: 0,19%	**14**: 0,19%	**15**: 2,42%	**16**: 1,82%	**17**: 0,57%	**18**: 0,61%
500 > H ≥ 400	**19**: 0,17%	**20**: 1,32%	**21**: 2,65%	**22**: 2,05%	**23**: 0,58%	**24**: 0,54%
400 > H ≥ 300	**25**: 0,16%	**26**: 1,28%	**27**: 2,91%	**28**: 2,62%	**29**: 0,84%	**30**: 0,72%
300 > H ≥ 200	**31**: 0,13%	**32**: 1,20%	**33**: 3,10%	**34**: 3,31%	**35**: 1,23%	**36**: 1,18%
200 > H ≥ 100	**37**: 0,09%	**38**: 0,93%	**39**: 2,95%	**40**: 4,01%	**41**: 1,97%	**42**: 3,86%
H < 100m	**43**: 0,04%	**44**: 0,41%	**45**: 1,67%	**46**: 3,37%	**47**: 2,59%	**48**: 12,20%

Figure 2. Criterion table with 48 combinations of Slope and Height, area percentages and M/S/P characterization.

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

With this classification, the resulting area (i.e., actual and not municipality –based) classification for the country is:

Mountainous:	37,87 %
Semi-Mountainous:	30,46 %
Plane:	31,67 %

Fitting closer the actual relief picture shown in the histograms.

Based on this criterion table, all cells are classified (Step 4). Overlaying each municipality polygon with the classified cells, results into three (M/S/P) numbers of cells (or percentages) for each polygon (Step 5). DEM needs not to be used again. These percentages are used to compute the weighted relief index R_i for each municipality (Step 7).

4.4 Overall characterisation
For an objective characterization, this step employs two tools:

- The first is the computation of a weighed relief index R_i for the terrain, for each municipality, based on the 3 percentages of cells in each category (M/S/P).
- The use of a ternary diagram (7) for positioning each R_i, which subsequently determines the final characterization for the municipality.

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

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

Obviously, $10 \leq R_i \leq 30$. The greater the M percentage, the higher the R_i 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

For the analysis and illustration of three complementary percentages, a very powerful visual tool is the ternary diagram (7) (Fig. 3).

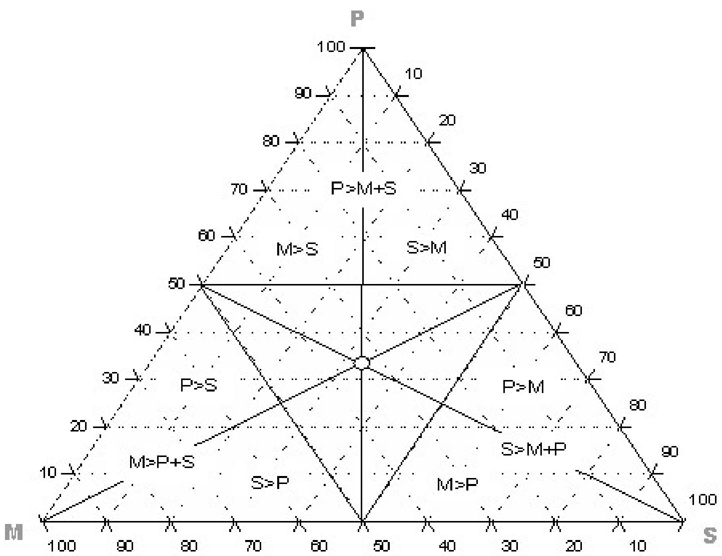

Figure 3. A general ternary diagram illustrating boundary M/S/P cases.

There are three axes for the %M, %S, %P percentages. Since each municipality is expressed by a triplet %M, %S, %P, it can be positioned somewhere in the triangle. The closer the point to a corner, the clearer the characterization. Some of these cases are shown in the diagram.

If we try to show the thresholds/boundary values expressed earlier, these actually show as straight lines (Fig. 4), forming three regions. One bottom left, where R_i *mountainous* values fall (shown in orange), a middle region (shown in yellow) where R_i *semi-mountainous* values fall, and thirdly an upper right region (shown in green) where R_i *plane* values fall. Once the R_i index is computed for each municipality, the latter can be displayed in the ternary space as points, classified as M/S/P. This result is displayed in Fig. 5.

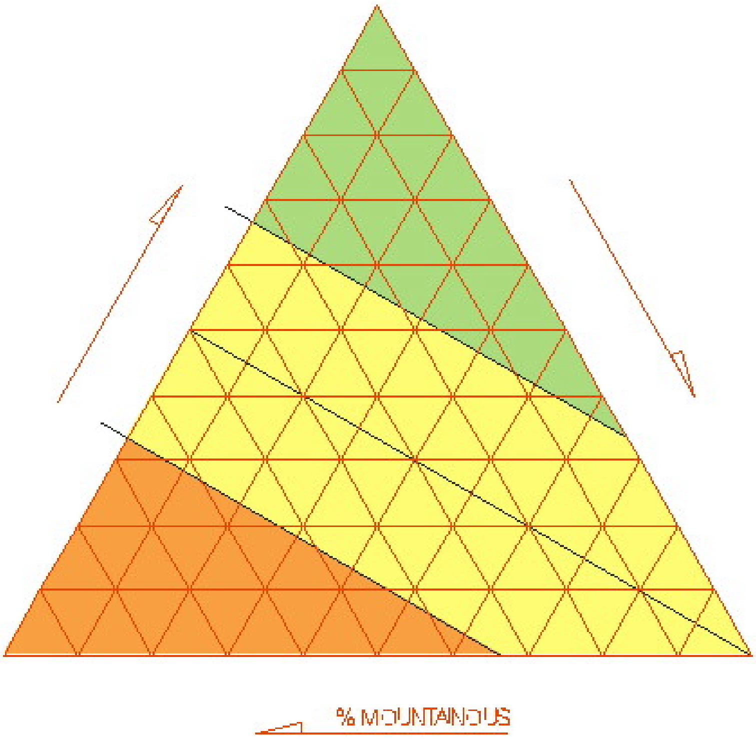

Figure 4. M/S/P Regions of influence in the ternary diagram.

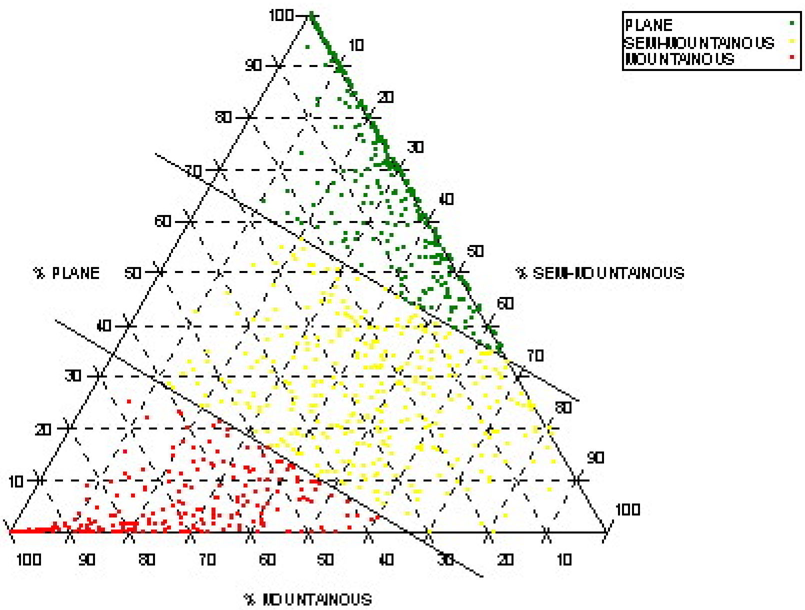

Figure 5. Spatialization of the 1034 municipalities in the ternary diagram, according to their %M, %HS, %P percentages.

5. MAP RESULTS

The map results of the method are shown below. Specifically, the first map (Fig. 6) shows a relief map at a characterized cell level. The second map (Fig. 7) shows the characterized municipalities.

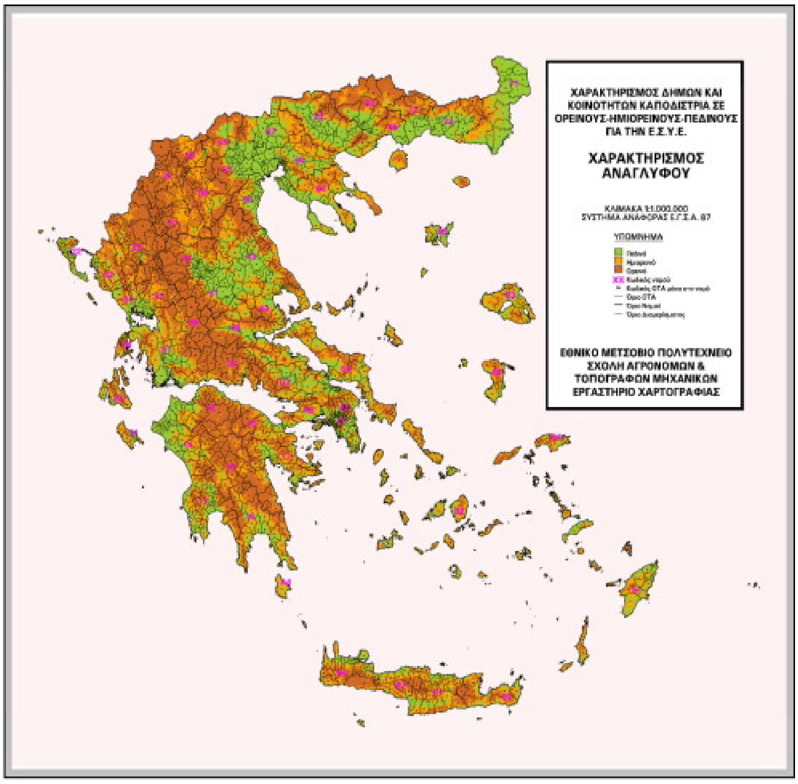

Figure 6. A relief map at a characterized (M/S/P) cell level.

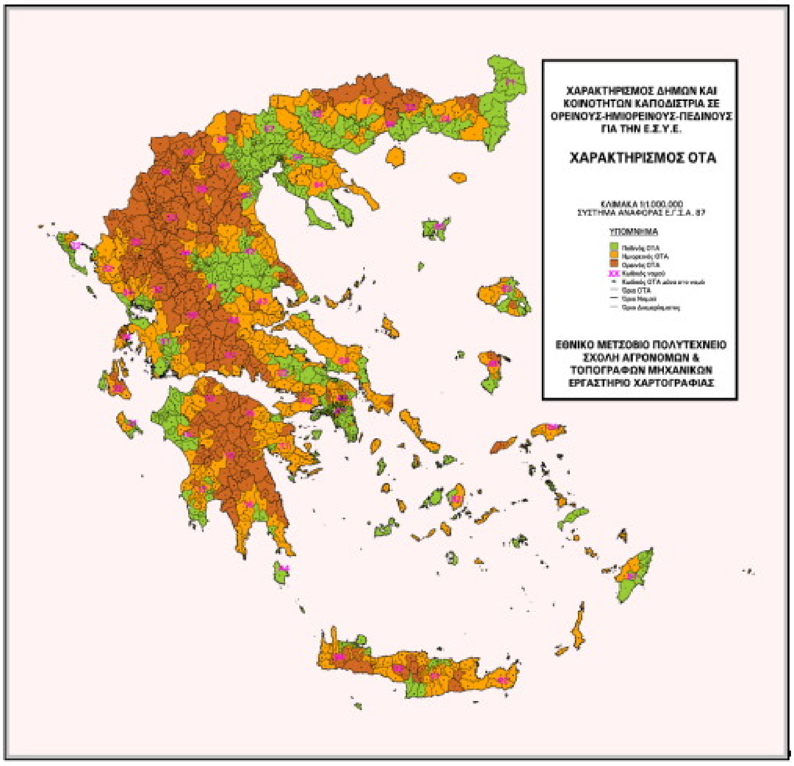

Figure 7. Map with characterized municipalities as M/S/P.

6. CONCLUSIONS

Besides providing a single final characterization (M/S/P) for each Municipality or Community, the method calculates important individual internal information for each area. It assigns values into 48 categories (combinations) of slope/elevation, describes ranges of elevations and slope, average elevation and slope, and finally calculates individual percentages in three categories M/S/P for each Municipality or Community. Then, using two techniques (a) a weighed characterization relief index, and (b) of ternary diagram, it leads to a global characterization M/S/P for each Municipality. The method was developed and optimised after being tested in representative regions of Country. Also, comparison with previous characterisations revealed sometimes systematic, other times profound gross "errors".

Two visualisation techniques were employed to present the results of the characterisation. The first is a series of traditional relief-type maps which do not however portray elevation but the weighed characterisation index. The second technique is the ternary diagram itself, which is a spatialization method relocating area-points according to their relief characterisation. This second product proves to be very useful in detecting similarities and dissimilarities among the different areas in question.

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Nikolaos Tzelepis was born in Athens in 1969. In 1994 he graduated from the School of Rural & Surveying Engineering, National Technical University of Athens. He is graduate student of the School of Rural & Surveying Engineering, National Technical University of Athens. Currently, he serves as Research Associate in the same University. His research interests are related to Cartographic Visualization and Hill-Shading. He is author of more than 5 papers related to Cartography and Geo-Informatics.