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LANDFORM CLASSIFICATION USING GIS TECHNIQUES. THE CASE OF KIMI MUNICIPALITY AREA, EUBOEA ISLAND, GREECE

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Abstract

The main objective of this paper is to classify landforms in Kimi municipality area of Euboea Island, Greece using advanced spatial techniques. Landform categories were determined by conducting morphometric analysis through the use of advanced GIS functions. In particular, the process of classifying the landscape into landform categories was based on Topographic Position Index (TPI).
The main topographic elements such as slope inclination, aspect, slope shape (curvature), topographic wetness index and stream power index were obtained from the DEM file of the study area. Landform classification was obtained using TPI grids and the classes were related with the geological pattern and the land cover by sophisticated spatial analysis function.
The knowledge obtained from the present study could be useful in identifying areas prone to land degradation and instability problems in which landforms are identified as an essential parameter.
Key words: *Landforms, morphometric analysis, TPI, DEM, Kimi Euboea.*

Περίληψη

Ο κύριος στόχος της παρούσας εργασίας είναι η ταξινόμηση των γεωμορφών στην περιοχή της Κύμης Εύβοιας, με τη χρήση προηγμένων τεχνικών χωρικής ανάλυσης. Οι γεωμορφές προσδιορίστηκαν με την μορφομετρική ανάλυση χρησιμοποιώντας τις προηγμένες λειτουργίες των Γεωγραφικών Πληροφοριακών Συστημάτων. Ειδικότερα, η διαδικασία ταξινόμησης των γεωμορφών σε κατηγορίες βασίστηκε στον υπολογισμό του Τοπογραφικόυ Δείκτη εντοπισμού (Topographic Position Index, TPI). Τα κύρια τοπογραφικά στοιχεία, όπως οι κλίσεις, η διεύθυνση μορφολογικών κλίσεων, η καμπυλότητα καθώς και οι Τοπογραφικοί Δείκτες ύγρανσης (Topographic Wetness Index, TWI) και Ορμητικότητας ρεμάτων (Stream Power Index, SPI), προέκυψαν χρησιμοποιώντας το Ψηφιακό Υπόβαθρο Εδάφους (DEM) της περιοχής μελέτης. Οι κατηγορίες των γεωμορφών που προέκυψαν συσχετίστηκαν με τις κατηγορίες των χρήσεων γης και τις λιθολογικές ενότητες της περιοχής έρευνας.
Η γνώση που προκύπτει από την παρούσα μελέτη μπορεί να αποτελέσει χρήσιμο εργαλείο στον εντοπισμό περιοχών επιρρεπών σε προβλήματα αστοχιών, στα οποία η κατηγοριοποίηση των γεωμορφών διαδραματίζει ουσιαστικό ρόλο.
Λέξεις κλειδιά: *Γεωμορφές, μορφομετρική ανάλυση, Τοπογραφικός Δείκτης Θέσης, Ψηφιακό Μοντέλο Εδάφους, Κύμη Εύβοια.*

1. Introduction

The knowledge of the extension and distribution of the landforms, either complex such as ridges, hills and mountains or simple such as highly productive plains and valleys, is very important (Lindenmayer et al, 2006). Currently, there are several researches available which are aimed to the determination and classification of the landforms by using automatic or semiautomatic algorithms (Dehn et al., 2001; Shary et al., 2002; Schmidt et al., 2004; Bolongaro-Crevenna et al, 2005; Jordan et al., 2005; Dragut et al., 2006; Prima et al., 2006; Minár and Evans, 2008, Batuk et al., 2008, Tagil & Jennesse, 2008, Gercek, 2010).

From a geological and engineering geological point of view, landforms are of specific interest as they were created by geological processes (Karsten et al., 2009). Landforms that develop upon a particular kind of bedrock are related to its structural features such as bedding planes, joints, folds and faults and to its mineralogical composition. In terrain developed upon faulted and eroded sedimentary rocks, there is a strong relationship between rock type, structure, and the ensuing topography. Rock structure determines both major landforms and details of the landscape. Therefore, it is of great significance to determine landform categories and to relate them with geological aspects, land cover and landform classes in a landscape developed or affected by human activities. The existing landforms play a significant role in identifying areas prone to land degradation and instability. Geomorphometry provides a quantitative description of the shapes of landforms and is derived using a combination of mathematics, engineering and computer science (Tagil & Jennesse, 2008). The possibility of recognizing basic geomorphological features using Digital Elevation Models and Geographic Information Systems Techniques is examined by Gioti (2010) in the area of Antiparos Island, Aegean Sea. Adediran et al. (2004) also demonstrated the ability of the delineated landform elements to be overlaid on any digital map and imagery for further applied research using the application of GIS and multivariate statistical analysis in the area of Crete Island, Greece. In the past, geomorhometric properties were measured calculating the geometry of the relative position with a landform (Blaszczynski, 1997). The field was revolutionized by the computer manipulation of spatial arrays of terrain heights, or digital elevation models (DEMs), which can quantify and depict ground-surface form over large areas (Maune, 2001). Morphometric procedures are routinely implemented by commercial geographic information systems (GIS) and specialized software (Harvey and Eash, 1996; ESRI, 1997; Dikau and Saurer, 1999; Wilson and Gallant, 2000; Guth, 2001).

In this paper, landform categories were determined by conducting geomorphometric analysis through the use of advanced GIS functions, obtaining several topographic gradients from the DEM file of the Kimi area in, Euboea, Greece. These gradients were related with the geological pattern, the land cover and the landform classes by sophisticated spatial analysis function.

2. Materials and Methods

2.1. Geological Settings

Euboea is the second largest island of Greece and the third largest island of the Eastern Mediterranean sea. It is located eastern of Attica, along the eastern coast of continental Greece (Figure 1). Geologically speaking, in Euboea Island outcrop three tectonic units, the ‘Pelagonian Unit’, the ‘South Euboea Blueschist Belt’ and under these units, the ‘Almyropotamos Unit’ (Aubuin, 1957, Katsikatsos et al. 1986, Katsikatsos, 1991, Shaked et al. 2000). As presented in previous studies (Koumantakis et al, 2008, Ilia et al, 2008, Rozos et al., 2009, Ilia et al., 2010, Tsangaratos et al., 2011), the lithological formations that consist the wide research area are listed as follows (Figure 2):

- Quaternary deposits, which include bed river deposits, debris, fluviatile terraces and dilluvial depositions.

- Neogene sediments that consist of, calcareous and clayey marls with conglomerate intercalations, as well as base conglomerate.
- Volcanic rocks presented in the south - eastern part of Kimi with dacides - andesites.
- Flysch formation consists of clayey sales, sandstones, conglomerates and limestones.
- Ultrabasic rocks consist of peridotites, dounites and at places serpentinites.
- Carbonate formations usually Mesozoic limestones, and at some places, Palaiozoic ones.
- Granites are outcrop in the Western part of Kimi basin, and they are Carboniferous in age.

Figure 1 - Study area of Kimi, Euboea Greece.

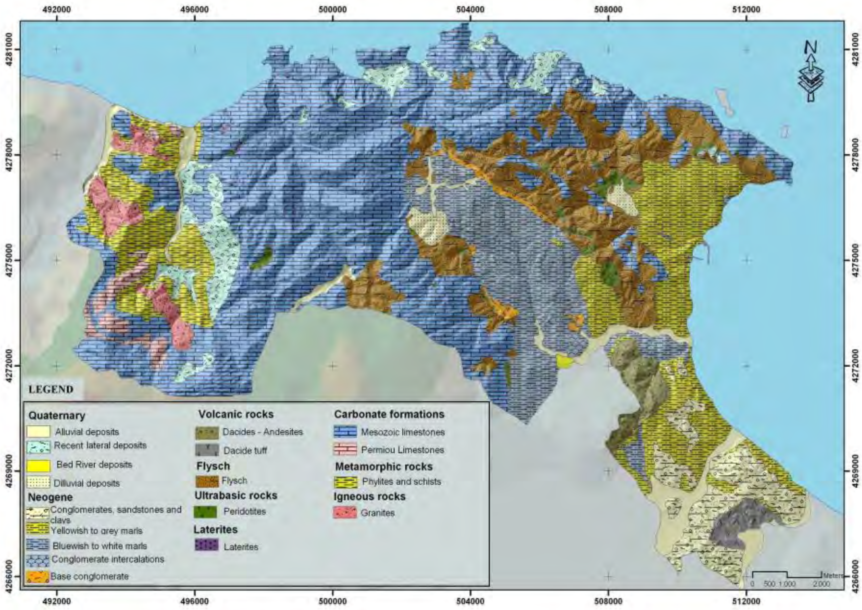

Figure 2 - Geological Map of Kimi Municipality.

2.2. Calculating Topographic Attributes

The methodology applied in the research area of Kimi, Euboea, Greece and uses the GIS techniques of the software programs ArcView 3.1 and ArcGIS 9.3. The analyzed data included the Digital Elevation Model (DEM) of the Ktimatologio S. A. with 5m resolution, a Geological map of the research area at a scale of 1:25000 (Ilia et al., 2008, Ilia et al., 2010) and the Corine Land cover of 2006 (European Environmental Agency, 2006) (Figure 2, 3). The DEM was used in order to compute the topographic parameters of elevation, slope inclination, aspect, curvature, topographic wetness index and stream power index (Figure 4). Slope inclination and aspect maps show the magnitude and direction of the vector tangent to the topographic surface pointing downhill at a point (Tagil and Jennesse, 2008). ESRI functions were used in order to calculate curvature based on the algorithms of Zevenbergen and Thorne (1987). A 3x3 cell neighbourhood represented the curvature of a 5x5 m area. Topographic Wetness and Stream Power Indices were used in order to quantify flow intensity and accumulation potential. Topographic Wetness Index (TWI) is also known as Compound Topographic Index (CTI) or Topographic Moisture Index (TMI). TWI at a particular point of the landscape is the ratio between the catchment area contributing to that point and the slope at that point (Wilson and Gallant, 2000):

Equation 1 – Topographic Wetness Index

$TWI = \ln(\text{catchment area}/\tan\beta)$,

where β=slope in radiants. Higher positive values are wetter and lower negative values are drier.

The Stream Power Index (SPI) was calculated as:

Equation 2 – Stream Power Index

$SPI = \text{catchment area} \times \tan\beta$,

where β=slope in radiants (Moore et al., 1993).

The SPI is closely related to the Topographic Wetness Index and is used in order to estimate the erosive power of the terrain.

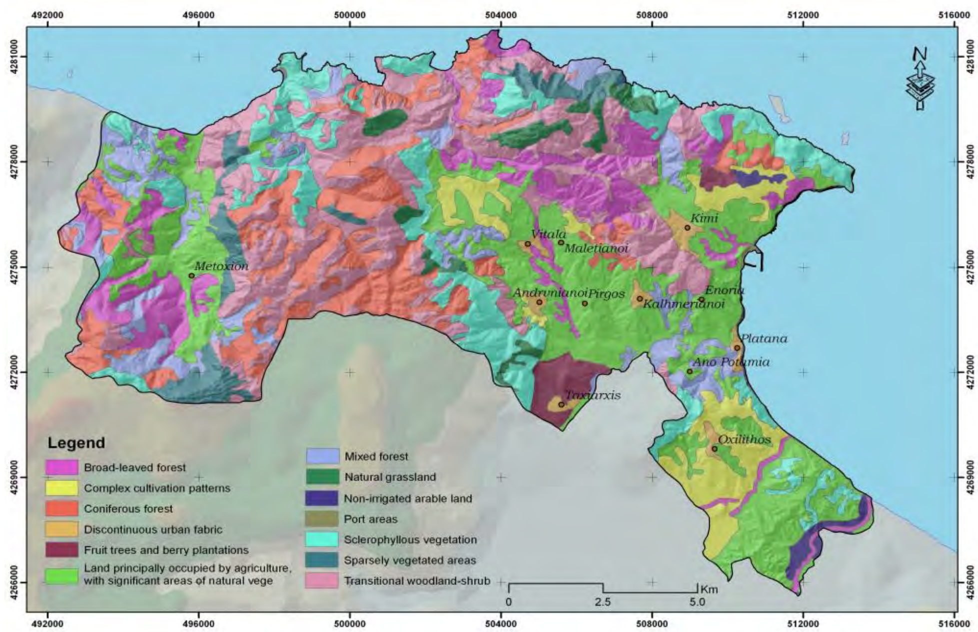

Figure 3 – Land cover classes classified from Corine 2006.

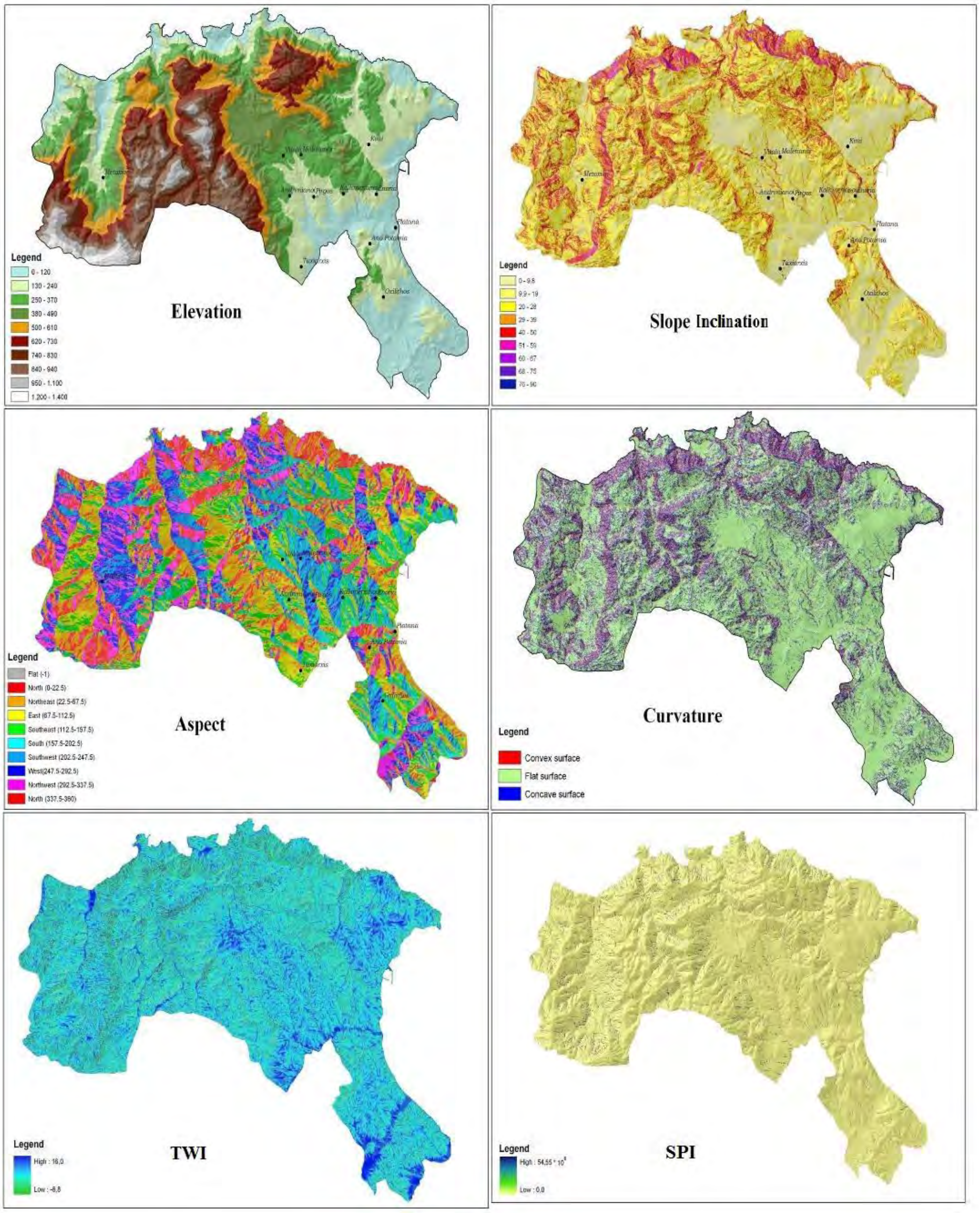

Figure 4 - Topographic attributes: elevation, slope inclination, aspect, curvature, topographic wetness index and stream power index.

2.3. Calculating TPI

Topographic Position Index (TPI) is the difference between the elevation at a cell and the average elevation in a cell surrounding that cell. Local mean elevation is subtracted from the elevation value at centre of the local window. An algorithm is provided as an ESRI script by Jenness Enterprises (Jenness, 2006) and it has local window options, which are rectangular, circular and annulus in shape. Positive TPI values represent locations that are higher than the average of the local window e.g. ridges. Negative TPI values represent locations that are lower e.g. valleys. TPI values near zero are either flat areas (where the slope is near zero) or areas of constant slope (where the slope of the point is significantly greater than zero), high positive values relate to peaks and ridges (Gercek, 2010).

The neighbourhood size and shape is critical to that analysis and is based on the scale of landscape feature being analyzed. To classify very small features, small neighbourhood is used. To identify large canyons or mountains, we use large neighbourhood (Figure 5).

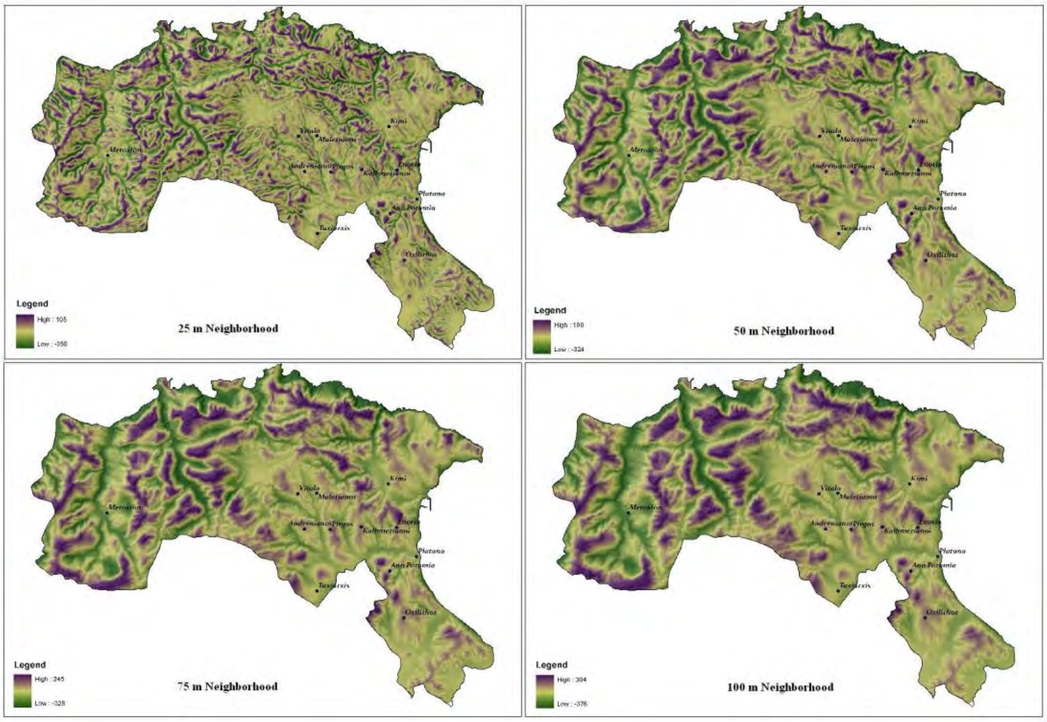

Figure 5 - TPI grids using 4 different neighbourhoods.

2.4. Landforms Classification

TPI values calculated from two neighbourhood sizes provide more information about the general shape of the landscape than the TPI values from a single neighbourhood and therefore, more complex landscape features can be identified by combining TPI grids generated at different scales (Tagil and Jenness, 2008). Combining TPI at a small and large scale allows a variety of nested landforms to be distinguished (Figure 6).

As a general rule, since elevation tends to be spatially auto correlated, the range of TPI values increases with scale. One method to address this problem is to standardize the TPI grids to mean = 0 and stdev = 1. This lets the same basic equations to be used to classify any scale combinations of TPI grids (Weiss, 2001).

In our case, 25 and 100 m grid in combination with slope were used and classified landforms using criteria described by Weiss (2001). The high and low TPI values were distinguished by setting a threshold of ±1 SD, (SD, standard deviation). A full description of each morphological classification is described by Weiss (2001) and Jenness (2006).

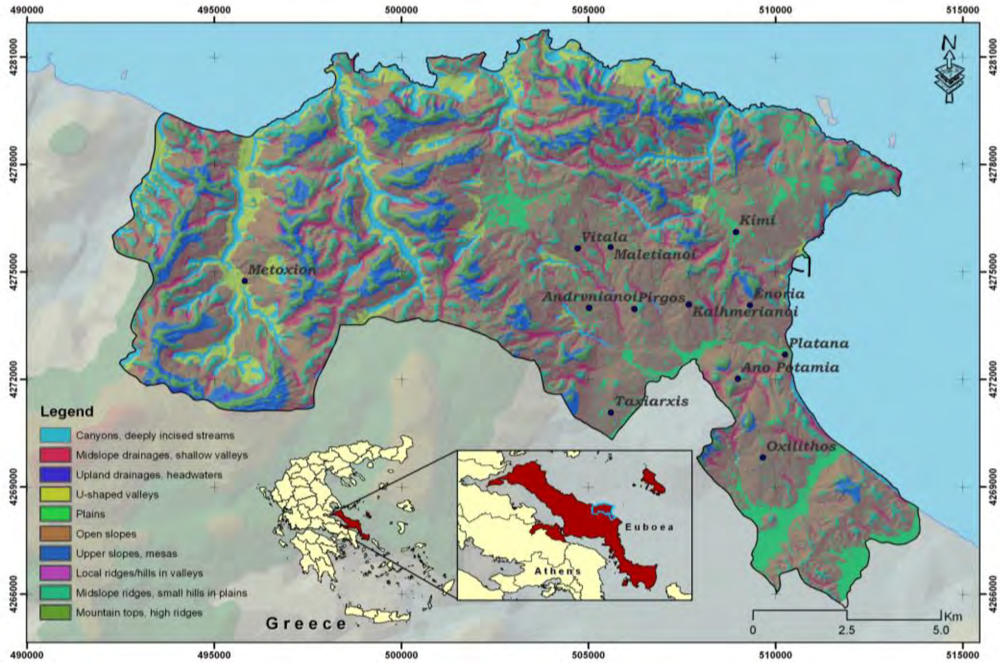

Figure 6 - Landforms using Weiss (2001) classes based on 25 m neighbourhood.

3. Results and Discussion

In Figure 7, the percentage of each landform class that covers the research area is provided. Furthermore, the ground truthing was verified by field surveys. The figure shows that the ~54% of the study area is classified as Open slopes, followed by Upper slopes (~7.3%), Mountain tops, high ridges (~7.2%), Canyons and deeply incised streams (~6.9%) and the other landform classes in smaller percentages. This is attributed to the fact that the area is intersected by several rivers.

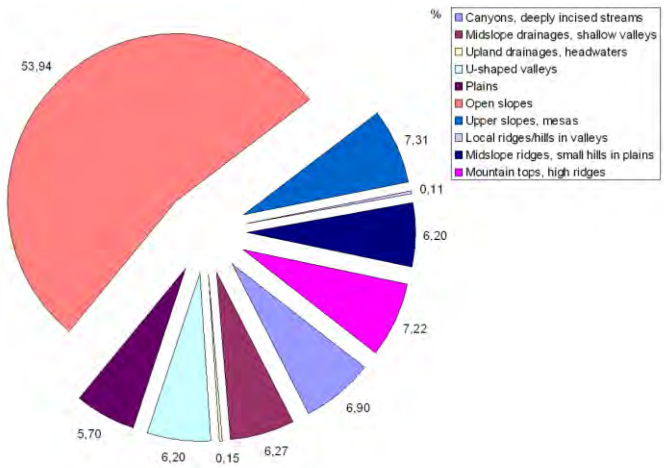

Figure 7 - Landforms using Weiss (2001) classes based on 25 m neighbourhood.

In Tables 1 and 2, the land cover and the lithological units were related with the landform classes, while in Table 3 it is presented the proportion of the lithological units in each landform class.

More specifically, as seen in Table 1, canyons and deeply incised streams (L1) appear to be covered by forest and Transitional woodland-shrub (69.86%), plains and open slopes (L5 and L6) are covered by land principally occupied by agriculture, with significant areas of natural vegetation (37.28 % and 31.72 % respectively) while upper slopes, mesas (L7), local ridges/hills in valleys (L8), midslope ridges, small hills in plains (L9) and mountain tops, high ridges (L10) appear mostly in transitional woodland-shrub (30.82 %, 36.82 %, 27.62 %, 35.28 % respectively).

Concerning the correlation between the lithological units and the landform classes (Tables 2, 3), it seems that the Quaternary deposits (alluvial deposits, dilluvial deposits, bed river deposits) appear mostly in plains, the marly formations (conglomerates, sandstones and clays, yellowish to gray and bluish to white marls), flysch formations, philites - schists and peridotites appear mostly in open slopes. These areas are prone to slope instability problems and comprise structurally controlled topography, depending on the resistance to weathering and erosion, factors that are interrelated to the mineralogical composition, the cementation, the bedding planes and joints. The recent lateral deposits appear mostly in U-shaped valleys, since they are broken down relatively rapidly by weathering and produce strongly linear or stepped topography.

Table 1 – Landform classes in relation with land cover units (%).

LandForm classes	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
Canyons, deeply incised streams (L1)	0.03	0.13	0.00	0.02	0.21	10.29	14.67	18.94	11.89	0.64	14.78	24.36	4.05
Midslope drainages, shallow valleys (L2)	0.30	0.14	0.01	0.44	0.41	9.79	13.76	24.01	12.16	1.13	13.57	19.40	4.89
Upland drainages, headwaters (L3)	0.00	0.00	0.00	0.00	0.00	0.12	8.15	17.55	3.66	0.00	21.41	8.54	40.57
U-shaped valleys (L4)	0.00	0.26	0.00	0.00	0.19	24.28	11.72	12.03	14.05	1.04	11.21	21.54	3.68
Plains (L5)	3.71	0.12	7.98	2.08	25.09	37.28	10.19	2.21	3.18	0.37	3.45	4.00	0.32
Open slopes (L6)	1.93	0.03	0.71	2.77	7.71	31.72	9.85	11.02	7.02	1.53	10.05	13.68	1.99
Upper slopes, mesas (L7)	0.01	0.00	0.00	0.00	0.47	5.44	6.59	17.83	4.52	7.14	17.18	30.82	10.00
Local ridges/hills in valleys (L8)	0.00	0.00	0.00	0.00	0.00	0.11	0.60	11.23	1.42	6.47	23.95	36.82	19.40
Midslope ridges, small hills in plains (L9)	0.40	0.00	0.07	0.32	2.95	16.02	10.53	12.74	7.69	1.82	17.95	27.62	1.90
Mountain tops, high ridges (L10)	0.00	0.00	0.00	0.03	0.26	5.55	5.18	11.88	4.31	8.12	21.21	35.28	8.19

C1: Discontinuous urban fabric, C2: Port areas, C3: Non-irrigated arable land, C4: Fruit trees and berry plantations, C5: Complex cultivation patterns, C6: Land principally occupied by agriculture, with significant areas of natural vege, C7: Broad-leaved forest, C8: Coniferous forest, C9: Mixed forest, C10: Natural grassland, C11: Sclerophyllous vegetation, C12: Transitional woodland-shrub, C13: Sparsely vegetated areas.

Table 2 – Landform classes in relation with lithological units (%).

Landform classes	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17	G18
L1	5.90	4.21	0.00	0.17	0.00	4.3	1.57	0.00	0.40	0.03	0.00	8.41	0.72	0.00	61.93	2.15	6.78	3.42
L2	0.86	0.23	0.00	0.24	1.66	5.3	6.79	0.00	0.27	3.26	0.41	14.97	1.74	0.12	56.07	1.35	4.72	2.02
L3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.00	4.29	0.00	0.00	88.10	0.00	2.93	4.22
L4	7.94	8.60	0.00	0.58	0.00	1.48	1.09	0.00	0.50	0.00	0.00	4.50	0.93	0.07	60.27	1.59	8.79	3.67
L5	26.54	0.22	0.97	3.50	6.86	13.5	25.70	0.16	0.83	0.32	2.43	7.78	0.95	0.02	8.82	0.13	0.76	0.48
L6	0.88	0.65	0.06	0.97	6.31	14.3	15.69	0.33	1.03	1.77	1.30	13.62	1.23	0.07	34.29	0.86	5.10	1.49

L7	0.00	0.00	0.00	0.00	2.05	0.27	0.08	0.00	0.00	1.89	0.00	7.11	0.29	0.14	79.53	1.76	5.29	1.60
L8	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	98.74	0.00	0.27	0.66
L9	0.26	0.35	0.00	0.19	5.67	4.25	4.11	0.00	0.28	1.09	0.78	13.87	0.53	0.02	54.87	2.89	7.42	3.42
L10	0.00	0.00	0.00	0.00	0.88	0.13	0.36	0.00	0.00	3.61	0.00	6.90	0.26	0.40	79.51	2.09	4.09	1.76

G1: Alluvial deposits, G2: Recent lateral deposits, G3: Bed River deposits, G4: Dilluvial deposits, G5: Conglomerates, G6: Yellowish to gray to white marls, sandstones and clays, G7: Bluewish to white marls, G8: Conglomerate intercalations, G9: Base conglomerate, G10: Dacides - Andesites, G11: Dacide tuff, G12: Flysch, G13: Peridotites, G14: Laterites , G15: Limestones, G16: Limestones Permiou, G17: Phyllites and Schists, G18: Granites.

Table 3 – Lithological units in relation with landform classes (%).

Lithological units	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**	**L10**
Alluvial deposits (G1)	13.79	1.82	0.00	16.69	51.08	16.07	0.00	0.00	0.54	0.00
Recent lateral deposits (G2)	23.73	1.20	0.00	43.60	1.02	28.68	0.00	0.00	1.76	0.00
Bed River deposits (G3)	0.00	0.00	0.00	0.00	63.91	36.09	0.00	0.00	0.00	0.00
G8: Dilluvial deposits (G4)	1.46	1.86	0.00	4.51	25.04	65.62	0.00	0.00	1.51	0.00
Conglomerates, sandstones and clays (G5)	0.00	2.34	0.00	0.00	8.73	76.28	3.36	0.00	7.87	1.42
Yellowish gray to white marls (G6)	3.12	3.49	0.00	0.96	8.08	81.27	0.21	0.00	2.77	0.10
Bluish to white marls (G7)	1.00	3.93	0.00	0.62	13.51	78.28	0.05	0.00	2.36	0.24
Conglomerate intercalations (G8)	0.00	0.00	0.00	0.00	4.72	95.25	0.00	0.00	0.03	0.00
Base conglomerate (G9)	0.11	12.40	0.04	0.00	1.09	57.99	8.39	0.00	4.11	15.86
Dacides – Andesites (G10)	3.98	2.40	0.00	4.47	6.74	79.88	0.00	0.00	2.53	0.00
Dacide tuff (G11)	0.00	2.81	0.00	0.00	15.18	76.73	0.00	0.00	5.28	0.00
Flysch (G12)	5.06	8.18	0.06	2.43	3.85	64.05	4.54	0.00	7.50	4.34
Peridotites (G13)	4.93	10.79	0.00	5.70	5.37	65.93	2.13	0.00	3.28	1.89
Laterites (G14)	0.32	8.07	0.00	4.76	1.14	43.01	10.55	0.00	1.21	30.94
Limestones (G15)	9.34	7.68	0.29	8.18	1.10	40.46	12.72	0.24	7.44	12.55
Limestones Permiou (G16)	11.77	6.72	0.00	7.84	0.57	36.72	10.20	0.00	14.19	11.98
Phyllites and Schists (G17)	8.91	5.63	0.09	10.38	0.83	52.42	7.37	0.01	8.75	5.62
Granites (G18)	12.53	6.71	0.34	12.07	1.46	42.65	6.20	0.04	11.25	6.75

4. Conclusions

GIS techniques were used in order to classify landscape into landform categories, based on Topographic Position Index (TPI). By this method, morphological types were generated for a semi-automated derivation of landform elements according to Weiss (2001). Digital elevation model (DEM) of the research area was a helpful tool in the effort of recognizing landscape morphological characteristics. This study also shows that DEMs offer many more potential habitat descriptors than simply a set of elevation values. Since landforms were created by geological processes and influenced by the land cover, it is of great significance to classify landforms in terms of understanding the potential and constraints within the landscape associated with them. The classification results can be used in applications related to precision agriculture, land degradation studies and spatial modelling applications, where landform is identified as an influential factor in the processes under study.

5. Acknowledgments

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