GIS-based Approach to Analyse the Relationship between Land Units and Land Use in the Central Region of Portugal

Luís Quinta-Nova[1*)]

[1*)] Polytechnic Institute of Castelo Branco. School of Agriculture, Quinta da Senhora de Mércules, 6001-909 Castelo Branco. Portugal; email: lnova@ipcb.pt; https://orcid.org/0000-0002-8464-7527

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Abstract

Land units refer to coherent spatial areas characterized by a degree of homogeneity concerning certain properties like geology, soils, and climate. The Land use mosaic corresponds to a circumstantial layer representing the landscape's present state, depicting the present resource allocation factors. Nevertheless, the stable potential layer is related to the stable characteristics of each site and allows the identification of use constraints or potentials. In this study, we use a methodology based on the land unit concept to define a stable potential layer at a regional level. Therefore, land units were delimited for the Central region of Portugal, resulting from the combination of geomorphology, soil parent material, and bioclimatic influence. For each land unit representative sample areas were characterized in terms of their land use mosaic characteristics. For that purpose, selected landscape metrics were used to quantify the land use mosaic geometrical attributes: Shannon's Diversity Index, Edge Density, Mean Patch Size, and Number of Patches. The existing land use types were also quantified. Finally, a cluster analysis was performed to define groups of samples representing the land units with similar land-use mosaic types. The landscape metrics that best explain the influence of the permanent structure of the territory on the circumstantial structure of use are Shannon's Diversity Index, Edge Density, and Number of Patches. The highest diversity land cover patterns are located in formations with a lithology rich to very rich in silica under Mesomediterranean dry to subhumid climate. The validation of the previously defined land units confirmed the reliability of the proposed methodology, with most of the land units strongly influencing the land use mosaic. The delimitation and characterization of homogeneous land units are useful for the definition of soil suitability and for the choice of the most appropriate uses and activities by the stakeholders.

Keywords: GIS, land units, land use, portugal

Introduction

To represent the spatial organization of the landscape two main approaches have been proposed: a more synthetical, where the identification of homogeneous units focused the main attention of the studies, and another more analytical, where there are no preconceived geometrical objects and where different approaches from the more thematical and disintegrated to the more integrated could be identified and used [1].

Within the first group, the concept of Land Unit as "tract of land that is ecologically homogeneous at the scale level concerned" [2] constitutes a particularly good example of the manifold approaches proposed along the years. The second group of approaches shows, as referred, a wider variety of conceptual and practical characterization methods, from the simple overlay of different thematic maps to their complex operation to achieve the definition of synthetical entities, like the ones proposed by [3]. Parallel characterization methods like the Matrix, Patch, and Corridor framework proposed by [4], although very useful in the description of the functional role of the geographical entities.

In any case, the unsolved question aroused by all these methods is the existence of geographical entities with ecological significance in their content and function. These entities, present throughout the ecological theory in concepts like ecotope, and expressed through climate and soil factors are not yet identifiable through the existing methods. Trying to analyse the factors that determine the nature of a certain site, it is clear that they have different forms and times of influence. This diversity determines that the nature of a given site at a given moment must be considered from a dynamic perspective and, therefore, the derived concept of land unit or site character as the character of adjacent sites or areas showing stronger resemblances between themselves than in relation with all other neighbouring ones, must be adapted to this reality [5].

One way to try to systemize these different influences is to differentiate them between tendentially stable (e.g., geology) and tendentially circumstantial (e.g., land use or vegetation cover) within a given time referential. Such an approach should allow the identification of the different stabilities of each present land unit factor and the possible patterns of evolution and response to management alternatives or disturbance factors [6].

The ecological value of a landscape depends on the viability of the present ecosystems. This viability is a function not only of their characteristics (dimension, interior/edge ratio, relations with similar ecosystems, diversity, naturalness, degree of external stress) but also of its functional equilibrium in terms of the stability of its nature (the degree of disturbance of the stable long-term nature of the site that determines the existence of the ecosystem).

The consideration of these basic conditions forms the core of the assessment and evaluation methods, where equal attention is given to the stable environmental variables and functions and to the circumstantial structures of the present ecological organization of the landscape. The use of the structural classification of [4], adapted to characterize both stable and circumstantial ecological structures, has proven very resourceful in describing both informational levels.

The differentiation of stable and circumstantial organizational levels in the landscape was determined by the different nature of the influence of each environmental factor.

Considering these patterns of influence, the environmental characterization was performed at two levels: (1) Physical land units, based on the identification of discontinuities (borders) of the stable environmental factors (Geology, Climate, Soil, Landform, and hydrology), and (2) Land use mosaic, determining two sets of spatially referenced data.

In relation to land use mosaic analysis, a variety of landscape metrics are sensitive to the specific spatial arrangement of different cover types on a landscape consider, considering four components of landscape configuration: patches, edges, probability of adjacency, and contagion [7].

The study aimed primarily at defining the potential layer and their land units at a regional level resulting from the combination of geomorphology, soil parent material and bioclimatic influence. Subsequently, it is intended to relate the obtained land units with the landscape metrics extracted from the land use mosaic.

Materials and methods

The Beira Baixa region is an administrative division in eastern Portugal. The region covers an area of 4614.6 km^2 and has a population of 84 046 inhabitants. The study area includes four municipalities: Idanha-a-Nova, Penamacor, Vila Velha de Ródão, and Castelo Branco. This territory is mainly occupied by forest and agroforestry uses (60.8%) and agriculture (36.2%).

The spatial data sets for the study were obtained from the following sources:

- European Digital Elevation Model (EU-DEM), version 1.1 [8].
- Bioclimatological indexes maps [9].
- Map of soil parent material types [9].
- Land Cover Map of Portugal - COS2018 [10].

All layers were combined and interpreted using the ArcGIS 10.8 geoprocessing tools. The Land Units Map was obtained by overlaying the thematic maps representing the main physical factors, namely soils, bioclimatic units, and elevation (Figure 1).

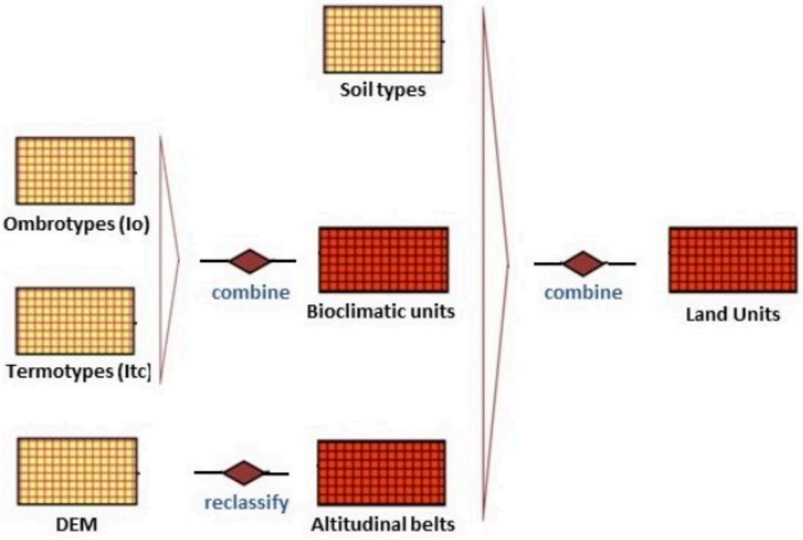

Fig. 1. Spatial Model used to produce land units.

The bioclimatological indices included in the analysis are those proposed in the World Bioclimatic Classification [11], and influence the spatial distribution of species populations and communities. To obtain the Bioclimatic units map the Spatial Analyst Tool was used to combine the raster themes ombrotypes and thermotypes.

Soil richness and texture are greatly related to the chemical composition and texture of the parent material. The map of soil parent material types represents different richness-textural classes based on the richness in SiO_2, K and Ca of the different rock formations and on grain size.

Altitudinal zonation describes the natural layering of ecosystems that occurs at distinct elevations due to varying environmental conditions [12]. Decreasing air temperature usually coincides with increasing elevation, which directly influences the species' composition in mountain areas.

Land Use Mosaic geometry was analysed using Patch Analyst extension from ArcGIS 10.8 on the Land Cover map, characterizing its composition and configuration. This extension includes measures related to patch complexity, configuration, and landscape diversity.

The landscape composition of each sample area corresponding to a given Land Unit was quantified by the percentage of area occupied by each land cover class (Figure 2). Landscape configuration was quantified through a wider set of metrics (table 1). Statistics describing the distribution of patch area such as Number of Patches (NP) and Mean Patch Size (MPS) were computed as they provide central tendency. Patch Density (PD) and Mean Shape Index (MSI) provide indications on the fragmentation degree of the different land cover types [13]. Additionally, the relative diversity of land cover classes within sample areas was determined using Shannon's Diversity Index (SDI). These metrics were chosen due to their widespread use in landscape analyses and well-documented effectiveness in quantifying spatial patterns [14, 15, 16].

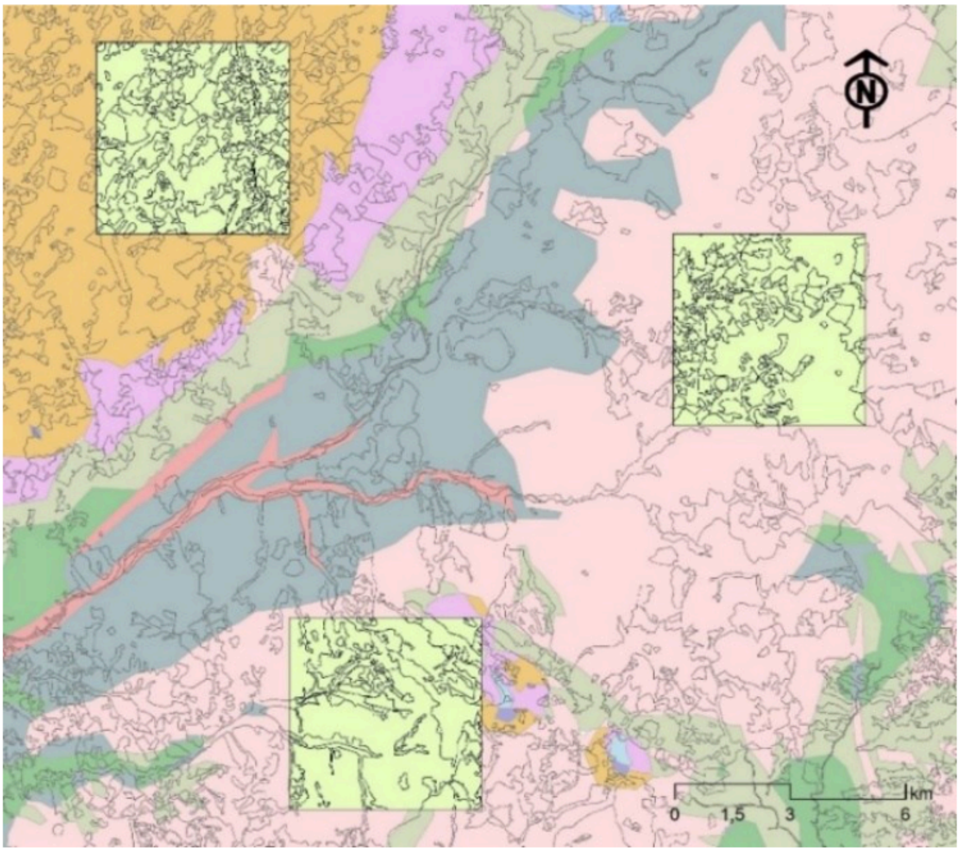

Fig. 2. Land cover sample areas corresponding to a given Land Unit.

To define groups of samples representing the land use mosaic types a cluster analysis was performed, and the clusters obtained were analysed in order to identify in terms of similar geometrical characteristics and land use dominant types.

Tab. 1. Landscape metrics used in the study.

Landscape Metric	Equation	Interpretation
Shannon's diversity index (SDI)	$SDI = -\sum_{i=1}^{m}\left(P_i \log_e l\right.$	Measure of relative patch density. The index will equal zero when there is only one patch in the landscape and increases as the number of patch types or proportional distribution of patch types increases.
Mean shape index (MSI)	$MSI = \frac{\sum_{i=1}^{n}\left(\frac{p_i}{2\sqrt{\pi * a_i}}\right)}{n}$	Measures the average patch shape (complexity) for a particular class or for all patches in the landscape
Edge density (ED)	$ED = \sum_{k=1}^{m} e_{ik}/A\ (10{,}000$	Standardizes edge to a per unit area basis that facilitates comparisons among landscapes of varying sizes.
Mean patch size (MPS)	$MPS = \frac{\sum_{i=1}^{n} a_i}{n} = \frac{A}{n}$	A function of the number of patches and total landscape area
Number of patches (NP)	$NP = n$	Gives the total number of patches in the landscape for a particular category.

Results and Discussion

The Bioclimatic map (Figure 3a) shows a strong influence of the Mediterranean climate in the region, which varies from Thermomediterranean Dry to Supramediterranean Humid. In terms of altitudinal belts, the basal level dominates, corresponding to about 67% of the region, with only 5% of the total area belonging to Montane and Altimontane belts (Figure 3b). Siliceous heavy lithology dominates (69%), corresponding to formations rich in silica, not so rich in bases (K and Ca), and very rich in clay and silt, which originate clayish soils (Figure 3c). Siliceous loamy formations also occupy an important area (28%), also very rich in silica, with abundant alkali feldspars usually rich in K and poor in Ca.

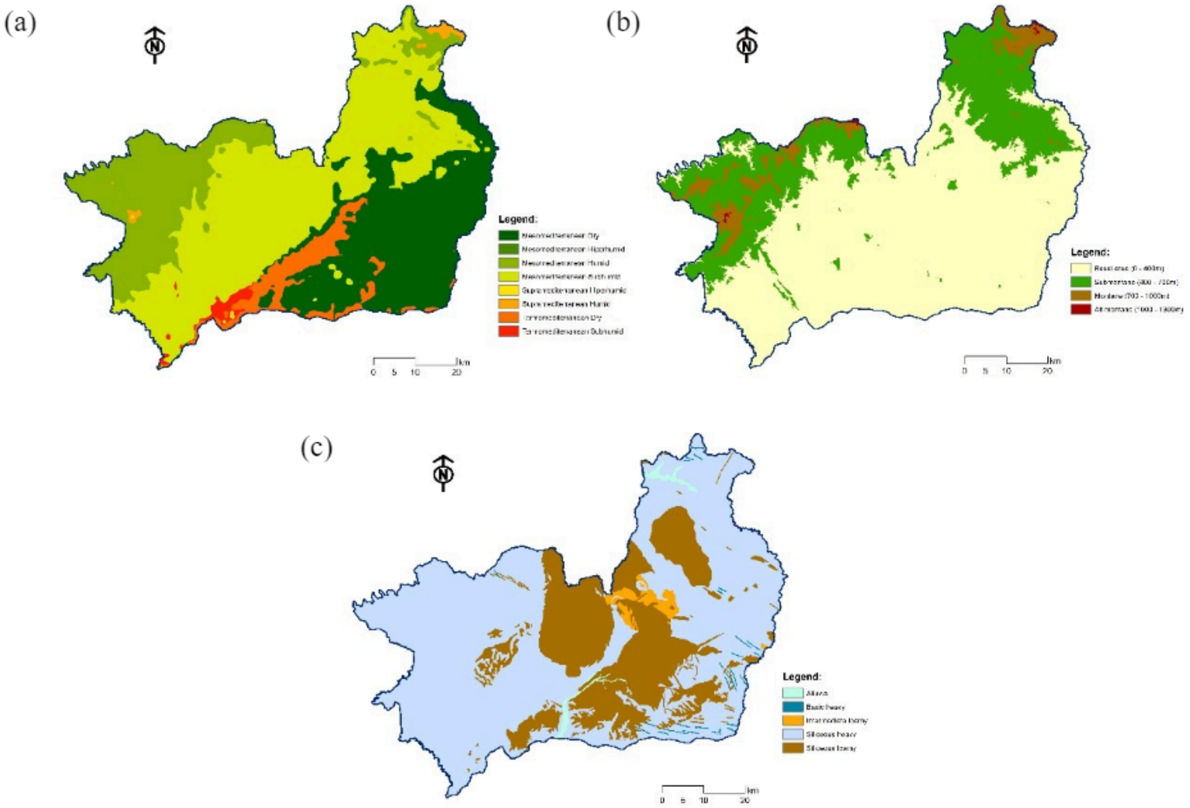

Fig. 3. (a) Bioclimatic Map; (b) Altitudinal belts Map; (c) Map of soil parent material types.

The resulting Land Units Map of Beira Baixa has 26 homogeneous units (Figure 4) representing combinations of main stable environmental factors that constrain the circumstantial structure of the landscape. These constraints are determined by a balance between the environmental demands of the different land uses and the large-scale ecological limiting factors.

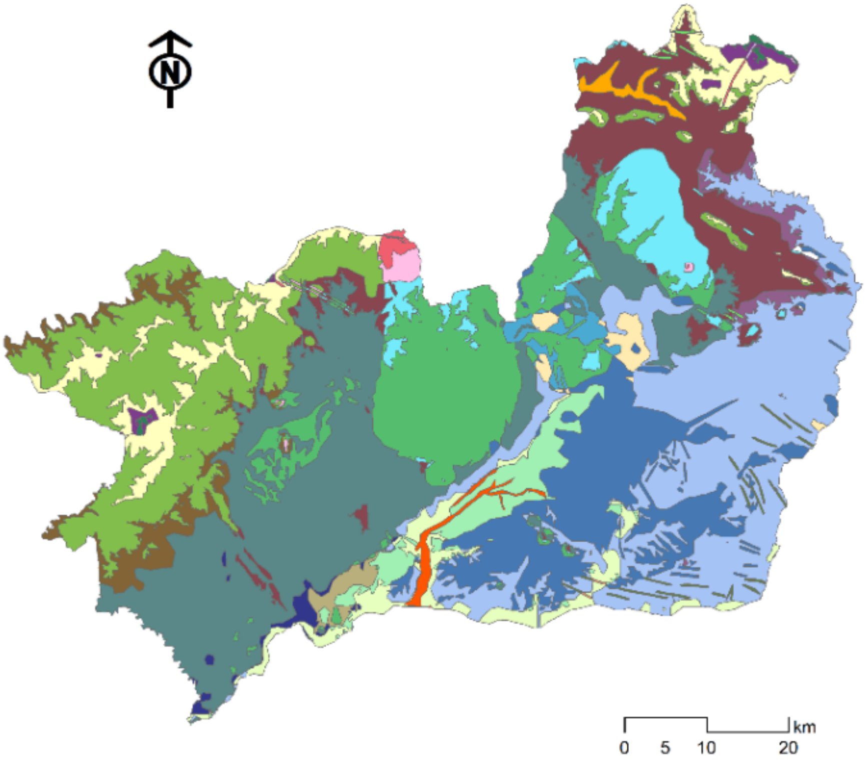

Fig. 4. Land Units Map.

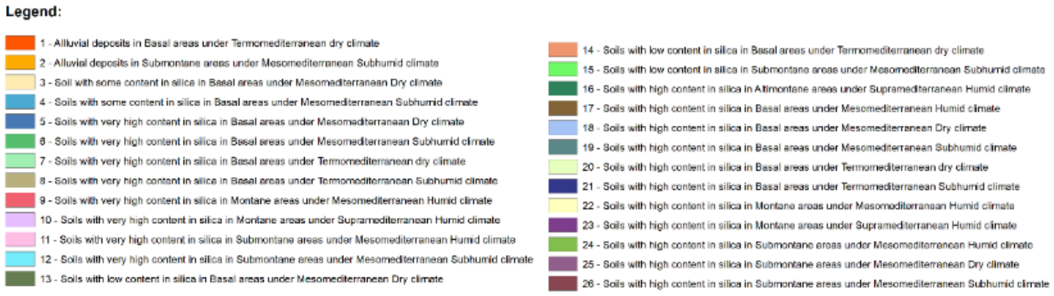

Fig. 4. Land Units Map.

Table 2 shows the average values for each landscape metric per land unit, with the highest values of land cover diversity and number of patches are associated to land units 6 and 12, and the edge density is higher for the land cover in land units 1, 11 and 12. Land units 4, 14 and 22 present the highest average land cover shape complexity. The highest mean patch size occurs in land units 7 and 23, associated with lower values of ED and SDI.

Tab. 2. Values of the landscape metrics (samples' average per Land Unit).

Land Unit	SDI	MSI	ED	MPS	NP
1	1,45	1,93	246,59	6,87	18,00
2	1,52	1,71	199,06	7,78	32,00
3	1,14	1,86	147,18	21,37	7,67
4	0,95	2,08	179,35	14,47	8,33
5	1,61	1,82	105,94	29,56	92,33
6	2,23	1,71	181,60	9,56	264,33
7	0,83	1,68	81,59	43,89	12,33
8	1,76	1,63	185,06	8,84	29,50
9	0,69	1,68	124,88	12,98	9,50
10	0,93	1,86	149,70	15,02	8,00
11	1,68	1,81	239,15	6,14	50,00
12	2,55	1,69	232,92	5,91	425,67
13	0,89	1,72	126,67	24,50	10,00
14	0,68	2,48	158,25	22,04	5,50
15	0,66	1,44	92,97	50,22	8,00
16	0,99	1,75	135,10	15,74	10,50
17	1,44	1,80	224,63	6,41	54,67
18	2,13	1,82	147,82	16,03	164,00
19	1,66	1,80	173,08	11,40	225,00
20	1,54	1,84	197,13	9,18	25,33
21	2,15	1,70	210,01	6,60	32,50
22	0,91	2,08	140,32	21,63	19,33
23	0,58	1,92	92,93	32,09	7,50
24	1,18	1,80	143,60	15,13	180,50
25	1,66	1,71	190,03	7,44	25,50
26	1,17	1,74	96,02	41,47	81,00

[a] Legend: SDI - Shannon Diversity Index; MSI - Mean Shape Index; ED - Edge Density; MPS - Mean Patch Size; NP - Number of Patches.

The result of the cluster analysis based on the landscape composition of each sample area corresponding to a given land unit is represented in the hierarchical clustering dendrogram (Figure 5).

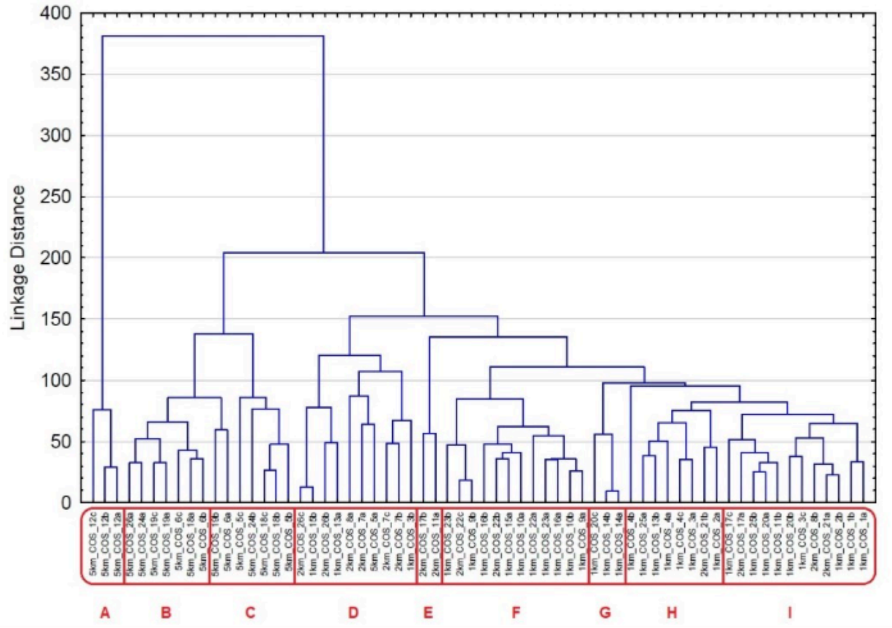

Fig. 5. Cluster analysis based on the landscape composition of each sample area corresponding to a given Land Unit.

Cluster analysis established a clear separation of clusters, with the following nine distinctive landscape structure types:

- Cluster A: Rock types/formations very rich in silica in Basal belt under the influence of Mesomediterranean dry climate. Diversified mosaic with high diversity of land uses. No dominant use. High ED. High NP and SDI.
- Cluster B: Rock types/formations rich in silica in Basal belt under the influence of Mesomediterranean subhumid climate. No dominant use. High to medium SDI. High to medium NP. High to medium ED.
- Cluster C: Rock types/formations rich in silica in Basal belt under the influence of Mesomediterranean dry climate. No dominant use. High to medium SDI. Medium ED.
- Cluster D: Rock types/formations very rich in silica in Basal belt under the influence of Thermomediterranean dry climate. Low-density *Quercus* sp. Stands (“Montado”) and annual crops dominance. Low to medium SDI. Low ED.
- Cluster F: Matrix of Rock types/formations rich and poor in silica in Basal belt under the influence of Mesomediterranean dry climate. Pine tree Forest and scrubland dominance. Low to medium SDI. Low ED and NP.
- Cluster G: Rock types/formations very rich in silica in Basal belt under the influence of Thermomediterranean dry climate. Holm oak woodland dominance. Low SDI. High MSI. Medium ED. Very low NP.
- Cluster H: Rock types/formations moderately rich in silica in Basal belt under the influence of Mesomediterranean subhumid climate. Low-density *Quercus* sp. Stands (“Montado”) and pasture dominance. High SDI. Medium MPS values. Low NP.
- Cluster I: Alluvions in Basal belt under the influence of Thermomediterranean dry climate - Rock types/formations rich in silica in Basal belt under the influence of Mesomediterranean humid climate - Rock types/formations rich in silica in Basal belt under the influence of Thermomediterranean dry climate. Scrubland dominance. Medium MSI. Low MPS values. Medium NP.

Conclusion

It can be concluded that there is a close relationship between land units and land use pattern in terms of dominance and configuration.

The landscape metrics that best explain the influence of the permanent structure of the territory on the circumstantial structure of use are Shannon's Diversity Index (SDI), Edge Density (ED), and Number of Patches (NP). The highest diversity land cover patterns with no dominant use are located in formations with a lithology rich to very rich in silica under Mesomediterranean dry to subhumid climate.

The delimitation and characterization of homogeneous land units are useful for the definition of soil suitability and for the choice of the most appropriate uses and activities by the stakeholders.

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