**MAPPING OF LAND UNITS AND LAND CAPABILITY CLASSIFICATION IN PORTUGAL**

**THE CASE OF LOURINHÃ MUNICIPALITY**

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**Abstract** – Land units can be an advantageous tool in landscape planning, in land suitability and land capability classification. It is vital to deepen the knowledge on their delimitation procedures, particularly in areas where available data is scarce and presents a certain complexity. Lourinhã municipality, based on sedimentary rocks, was chosen as a case study. Land units were mapped using geology (1:50 000), landforms and soils (1:25 000) information. Several inadequacies were observed both in the soil and soil capability maps[[4]](#endnote-1). There was evidence of a strong information deficiency on basic characteristics of soil units and the presence of rock outcrops was not revealed in such maps. From the geological units and landforms, 33 basic physiographic units were delimited, and their association with soil units resulted in an equal number of land units, afterwards generalized. The delimited land units have proven to be suitable for a land capability classification at the municipality scale, revealing great potential to identify the nature and severity of the major land (and soil) degradation risks. Also, they showed to be useful for improvement of the soil capability classificationi and to standardize the definition of the National Agricultural Reserve by using identical delimitation criteria.

**Keywords**: Landforms, Soils, GIS, Land classification, Landscape Planning.

**Resumo** – A delimitação de *unidades de terra* e a classificação da capacidade da terra EM Portugal. O caso do concelho de Lourinhã: Lisboa. As *unidades de terra* podem ser um instrumento vantajoso no ordenamento do território, na *avaliação da aptidão e da capacidade da terra*. É crucial aprofundar o conhecimento dos procedimentos da sua delimitação, nomeadamente em áreas onde a informação apresenta alguma complexidade. Como caso de estudo optou-se pelo concelho de Lourinhã, que assenta sob formações sedimentares. As *unidades de terra* foram mapeadas a partir da geologia (1:50 000), formas de relevo e solos (1:25 000). Observaram-se inadequações na carta de solos, bem como na respectiva carta de capacidade de uso do solo. Constatou-se uma forte deficiência de informação sobre as características das unidades de solos e os afloramentos rochosos não eram evidenciados em tais mapas. A partir das unidades geológicas e das formas de relevo delimitaram-se 33 *unidades fisiográficas básicas*, e a sua associação com as unidades de solos resultou em igual número de *unidades de terra,* posteriormente generalizadas. As unidades de terra delimitadas mostraram-se adequadas para a classificação da *capacidade da terra* à escala municipal, revelando um grande potencial para identificar a natureza e intensidade dos principais riscos de degradação da terra (e do solo). Além disso, provaram ser uma via adequada para o aperfeiçoamento da classificação da carta de capacidade de uso do solo e para a padronização da definição da Reserva Agrícola Nacional utilizando critérios de delimitação idênticos.

**Palavras-chave:** Formas de relevo, Solos, SIG, Classificação da terra, Ordenamento do território.

I. INTRODUCTION

Land units are an essential tool for several landscape planning applications as they express a “tract of land that is ecologically homogeneous at the scale level concerned” (Zonneveld, 1989: 68). Land units have also been used as a mapping tool and provide a basis for land suitability and land capability assessment (Zonneveld, 1989: 68; OEH, 2012).

Recent studies demonstrate that land units can be used as a main concept in the resolution of landscape planning issues. For instance, Blasi *et al*. (2008) used the land unit approach to design an ecological network of sites in the Rome Province (Lazio, Italy), in order to fulfill the main ecological needs of species, community and ecosystems. Also, Capotorti *et al*. (2012) used land units as a tool to describe the ecological classification of land in Italy and show how these units can act as reliable frameworks to implement national conservation strategies. In addition, the land capability mapping in Tasmania was developed using land units, that is, homogeneous units in terms of climate, relief, lithology and soils (Grose, 1999)

In Portugal, the land unit concept has been only partially developed in soil surveys associated with the evaluation of land suitability. Particularly, Agroconsultores and Coba (1991) in the elaboration of the Portugal Northeast soil map delimited *natural regions* corresponding to large landscape units combining physiographic features, climate, vegetation, land use and homogenous zones approaching to the land unit concept. Agroconsultores and Geometral (1995) for the Entre-Douro and Minho soil and land suitability maps at 1:100 000 scale, delimited large *morpho-climatic units*, relatively homogenous as to climate, lithology, geomorphology, topographical conditions, vegetation and land use. Meanwhile, Abreu *et al.* (2004) defined *landscape units*, at the national level, as areas where the landscape presents a specific pattern associated with a particular character, defined by geomorphology, lithology, soils, land use, farm dimension, human settlement pattern, climate, proximity of the sea and presence of important structures and infrastructures. Although the delimitation procedure of *landscape units* (Abreu *et al.*, 2004) is not quite clear, the concept adjusts itself to the land definition as expressed by FAO (2007).

Despite the scarce applications of the land unit concept in Portugal, the legislation regulating the National Agricultural Reserve (NAR) recognizes the need for the delimitation of homogenous areas defining land units and pointing out that “are part of the NAR the land units that present a high or moderate suitability for agriculture” (Decree-Law nº 73/2009, 31st March), classified “according to the classification methods of the land suitability classification recommended by the Food and Agriculture Organization (FAO)”. As large areas of Portugal still require for this classification, such law foresees that, when it is not possible to use the FAO classification, it is also possible to affiliate into NAR “the areas with soil capabilityi classes A, B and Ch”, or “alluvial or colluvial areas” or else areas where these classes are largely represented. Besides the absence of the classification recommended by FAO (1976, 2007) in most part of the country, the soil capabilitymapi shows deficiencies, namely in the littoral central region, where soil capabilityi units were not adequately framed with the general system of the Official Soil Service (SROA, 1973; IDRHa and SPCS, 2005).

Since the land unit concept is rarely used in Portugal and is considered in the legislation that regulates NAR areas, it is therefore crucial to implement the methodology regarding land units mapping and to evaluate whether NAR areas can be assessed, especially where the information is scarce and presents great complexity. In this context, a study was developed aiming to (i) analyze the land unit concept applicability, (ii) develop a methodology in areas where the existing data is considered insufficient, (iii) evaluate how much land units are in accordance with the existing soil capabilityi units, and (iv) assess whether the land unit delimitation can lead to a unifying methodology for the NAR delimitation. As a case study, Lourinhã municipality (an area based on sedimentary rocks) was chosen, since it is intensively used for agricultural purposes.

II. METHODOLOGY

1. **Study area**

The study was carried out in the Lourinhã municipality (39° 15′ 0″ N, 9° 19′ 0″ W) located in Portugal’s West Coast, part of the Lisbon district (fig. 1). It comprises an area of about 147 km2 with a population of ca. 25 000 inhabitants. The main economic activity is associated with agriculture, fisheries, food industry and extractive industry. The majority of the territory is used for agriculture; thence Lourinhã landscape is profoundly influenced by the agriculture activity (fig. 2), especially horticulture. The area exhibits mild temperatures, high relative humidity, and low frost risk in winter, providing adequate conditions for agriculture activity (Varela, 2008).

1. **Data Source**

Basic available data regarding the Lourinhã municipality was collected, organized and analyzed. The digital terrain model (DTM), Shuttle Radar Topography Mission (SRTM), resampled to a 30 pixel was used to calculate the slope gradient, hypsometry, altimetry and landforms, using the model implemented by Mendes (2010) model), following the specifications of Morgan and Lesh (2005). Geological information was gathered from the Portugal geological map (1:50 000) - sheets 26-D (Caldas da Rainha; Zbyszweski and Almeida, 1960), 26-C (Peniche; França *et al*., 1960), 30-A (Lourinhã; Manuppella *et al*., 1999) and 30-B (Bombarral; Zbyszewski, 1966). Information regarding soil was taken from the Portugal soil map (1:25 000) - sheets 337, 338, 349, 350, 361 e 362 (Direcção Geral da Agricultura e Desenvolvimento Rural, DGADR). The occupation and soil use map[[5]](#endnote-2) COS 2007 Level 2 (1:25 000) (DGT, 2007) and the soil capability mapi (1:25 000) (DGADR) were also used to support the analysis of land units.

1. **Reorganization of data and land unit delimitation**

The procedure for land unit delimitation (see flowchart of fig. 1) was adjusted to the available data for the study area, respecting the fundamental concepts introduced by Zonneveld (1995). After collecting basic available data, field observations were carried through. Following the field observations it was possible to aggregate and dimensioned the geological formations and landforms. Geological formations were aggregated into 11 geological units, the alluvial and colluvial areas being taken from the Portugal soil map, since its scale was more appropriated. Landforms were calculated and aggregated into four landform units. Soil information from the Portugal soil map (using the Portugal Soil Classification, PSC) (SROA, 1973; IHDRA, 1999) was inferred to the World Reference Base for Soil Resources (WRB, 2006) resulting into eight soil-mapping units. Geological units and landform units were intersected resulting in 33 basic physiographic units; to each of these units information regarding soil units, as a qualitative attribute, and rock outcrops were added. Therefore, 33 land units were obtained and afterwards grouped into 11 generalized land units.

*3.1. Climate*

Although the climate is a determinant attribute to qualify the land units (Zonneveld, 1995: 81), in the present study the land unit delimitation was mainly associated with the geology and landforms, as climate elements variation is relatively small. To analyze this attribute, data from the closest weather stations and/or pluviometric stations (Cabo Carvoeiro, Caldas da Rainha, Pragança and Torres Vedras) were used. The mean annual rainfall in Lourinhã may vary from 600 to 700 mm, since it is 566.6 mm in Cabo Carvoeiro, 608 mm in Caldas da Rainha and 780 mm in Torres Vedras (Reis and Gonçalves, 1981). It can be assumed that some variations occur, as the elevation ranges up to 200 m. The daily temperature range is relatively narrow, given the small difference between the mean maximum and the mean minimum temperature, either in the warmest month or in the coldest month. In Cabo Carvoeiro, the closest station to the ocean, the range is 4.5ºC in the warmest and 5.3ºC in the coldest month; in Caldas da Rainha the range is more pronounced: 8.5ºC in the warmest month and 7.7ºC in the coldest month, probably because of its greater distance to the ocean. The monthly mean relative humidity of the air is high and above 77% in Caldas da Rainha, and 81% in Cabo Carvoeiro; fogs frequently occur in summer (Varela, 2008).

* 1. *Geology*

The sheets 26C, 26-D, 30-A, 30-B of the Portugal geological map at 1:50 000 scale were appended, in order to obtain a geologic map of the study area. These sheets show a distinct legend and content, thus a geological map was derived from a simplification and aggregation of the geological formations, aiming to reach the closest uniformity to lithological units. Eleven geological units were delineated through the similarity described on the top of the lithological formations following the criteria of its topographical position, texture of the detrital or clastic sedimentary rocks and moreover the nature or composition of the rocks (calcareous or not calcareous). For the geological unit delimitation it was also used information of the Portugal soil map regarding the alluvial[[6]](#endnote-3) and colluvial areas, and also some information on the characteristics of the soil units assuming that of these (e.g. texture) may be associated with the grain size of rocks regarding different geological formations.

* 1. *Landforms*

The model implemented by Mendes (2010) used to identify the landforms follows the specifications proposed by Morgan and Lesh (2005) based on the Hammond (1954, 1964a, 1964b) procedure. This model was processed in ArcGIS using ESRI modelbuilder. To run the model it was necessary to define a parameter of the focal statistics tool, the pixel radius circular window. In this case, it was used a 15 pixel. The model is divided in four sub-models, three of them are related with the parameters set by Hammond (1954, 1964a, 1964b) - slope, relief and profile type - and the fourth sub-model reclassifies the results of the first three sub-models based on the local interpretation according to the field observations. For the reclassification of the final map it was essential to consider attributes (as slope, hypsometry, altimetry) including the geological formations to support the landforms delimitation.

* 1. *Soils*

The information of the Portugal soil map (SROA, 1973; IHERA, 1999) was extrapolated to the WRB (2006) system as shown in table I. It should be emphasized that the delimitation of soil map units in the Portuguese soil map was not supported by previous delimitation of basic physiographic units (landforms). Also, soil units identified in the study area generally reflect their relationship with the local soil parent material, and are not framed in the report of the geological map.

Several difficulties emerged with the analysis of soil data. The scale (1:25 000) suggests a detailed soil map, but it presents great spatial variability related to the soil parent material, as designations such as “fine sandstones, clays and claystones” or “fine and coarser interstratified sandstones” are used. Many soil units presented in the Portugal soil map are distinguished generally by the color, which is not necessarily related to different physical and chemical characteristics. Several soil units considered in the Portugal soil map are absent in PSC Handbook (SROA, 1973), lacking therefore of a general morphological description and a typified characterization (such as thickness and effective soil depth, horizons, texture, concentration of calcium carbonate, complex exchange characteristics...) other than their designation (IHERA, 1999). Although characteristics of some soil units in the soil map are shown in the PSC Handbook (SROA, 1973), morphological and analytical characterization details for the same units occurring in the area under study are not known. Given these difficulties to establish reliable inferences, the criteria used to define the soil-mapping units (Reference Soil Groups *sensu* WRB, 2006) were mostly associated with the possible soil profile differentiation, the calcium carbonate occurrence, the nature of limestone rocks and the topographical position. It is noteworthy that the soil available information is not sufficient for an accurate soil classification at first level within the WRB (2006) system.

Table I – Correspondence between soil families (Portugal Soil Classification, PSC; IHERA, 1999) and the Reference Soil Groups (WRB, 2006) in the Lourinhã municipality, and symbols of the resulting general soil-mapping units.

Quadro I – Correspondência entre as famílias de solos (Classificação dos Solos de Portugal; IHERA, 1999) e os Grupos de Solos de Referência (WRB, 2006) no município de Lourinhã e símbolos das unidades cartográficas gerais resultantes.

|  |  |  |
| --- | --- | --- |
| Soil Families (PSC) | Reference Soil Groups (WRB) | Soil-mapping units |
| Art; Ba; Lpt; Lpt(a); Lpt(a,h); Lpt(a,p); Lpt(p); Lvt; Lvt(a); Lvt(p); Paco(a); Pago; Pago(a); Pao; Pao(a); Patc(a); Pato; Pato(a); Pato(a,h); Pato(a,p); Ppt; Ppt(a); Ppr; Ppr(p); Pto; Vago; Vago(a); Vao(a); Vato; Vato(a); Vt(a); Vt(a,p); Vt(d); Vt(p); Vto(a). | Regosols, Cambisols. | 1A |
| Arc; Arct; Ec; Pcdc; Pcdc(a); Pcdc(a,p); Pcdc(p); Pcdc’(a); Pcsd(a); Pcsd'(a); Pcst; Pcst'; Pcst'(a); Pcst'(h); Vcst; Vcst(a); Vcd; Vcd(p); Vcdc(a). | RegolsolsB, Calcisols, LeptosolsB. | 2 |
| Bva; Pagc; Pc; Pcs; Pcs'; Pcs’(a,d,p); Spc(p); Spc'; Svc'; Vac'; Vac'(a). | Calcisols, RegosolsB. | 3C |
| A; A(h); A(i); Aa; Aac; Aac(h,i); Ac; Ac(h); Al(h); Alc(h); At; At(h); At(p); Atl; Atl(a); Atl(h); Ca; Cal; Calc. | Fluvisols. | 4 |
| Sbl(h); Sb; Sb(a); Sb(h); Sba; Sbac; Sbc; Sbl; Sbl(a,h). | Regosols, Fluvisols. | 5 |
| Rg; Rgc. | Arenosols. | 6 |
| Ap; Ap(a); Pz; Pz(a). | Arenosols, Regosols, Podzols. | 7 |
| Asoc | Social Area. | Social Area |

(a) - agropedic phase; (d) - shallow phase; (h) - hydromorphic phase; (i) - flooded phase; (p) - stony phase.

A May include small areas of Leptosols and eventually Luvisols and Vertisols.

B Generally can be qualified as calcic.

C May include small areas of Luvisols and Vertisols

1. **Land units**

In the present case study, the concept of *basic physiographic units*, a concept already developed in some soil maps of Portugal (Agroconsultores and Coba, 1991; Agroconsultores and Geometral, 1995), was used to support the delimitation of land units. Those units resulted from the intersection of geological units and landform units; after the intersection it was also necessary to eliminate the small sliver polygons that resulted from the intersection. The *Basic physiographic units* were used to frame the information regarding soils and rock outcrops in order to delimitate the land units. After framing the information concerning the soil attribute and presence or absence of rock outcrops with the *basic physiographic units*, land units were obtained as a result. Thus, land units were described by geology, landforms, soils and presence/absence of rock outcrops. Additionally, the resulting land units had to be generalized in order to compare them with the soil capability mapi. Thus, the texture and hardness of the lithological materials, topographical position and presence of rock outcrops were used as criteria for land unit assessment.

III. RESULTS

1. **Geological units**

As reported in table II and figure 4, eleven geological units resulted from the aggregation of the geological formations reported in the Portugal geological map. The *a* geological unit includes the alluvial (and colluvial) areas surrounding the main watercourse network, and is defined by its topographical position and comprises an area of 1454.73 ha.

The A (24.87 ha) and D (38.12 ha) geological units are defined by its location and are associated to sandy beach and dunes, respectively. The E geological unit corresponds to the Lourinhã oldest geological formation (Dagorda marls and dolomites), covering an area of 109.24 ha.

Both F and K geological units are located in the Cesareda tableland and are distinguished from each other by the nature of their lithological materials; the former (860.62 ha) includes calcareous formations in thick benches, while the latter (752.21 ha) comprises marls and sandy limestones.

The unit G is the largest unit of the area (9240.51 ha) includes materials corresponding to sandstones (variable grain size), marls, and some formations composed by clays and siltstones, and gravels.

The unit I (1835.1 ha) marks the transition between the G and K geological units. This unit is distinct from the former G for presenting apparently a homogeneous texture composed by quartzitic sandstones, and from the K by the absence of calcareous materials.

In the southern part of the Lourinhã municipality area, the M geological unit includes another calcareous formation (Vimeiro limestones), comprising an area of 69.66 ha.

Finally, N and J units, both located in the typhonic valley of Bolhos (Manuppella *et al*., 1999), distinguished themselves by the consolidation and maybe grain size of the lithological formations: the unit N (206.06 ha) corresponds to sandy deposits, whereas the unit J (125.49 ha) is associated with sandstones.

Table II – Description and areas of the generalized geological formations defined for the Lourinhã municipality.

*Quadro II – Descrição geral e áreas das formações geológicas generalizadas definidas para o concelho de Lourinhã.*

|  |  |  |  |
| --- | --- | --- | --- |
| General geological units | General description | Area (ha) | Percentage\*(%) |
| *a* | Alluvium, Colluvium | 1454.73 | 9.88 |
| A | Beach sands | 24.87 | 0.17 |
| D | Dunes | 38.12 | 0.26 |
| E | Dagorda marls and dolomites | 109.24 | 0.74 |
| F | Cesareda and Cabreira limestones | 860.62 | 5.85 |
| G | Bombarral gravels, marls and clays, sandstones and siltstones | 9240.51 | 62.79 |
| I | Quartzitic sandstones | 1835.1 | 12.47 |
| J | Sandstones | 125.49 | 0.85 |
| K | Marls and sandy limestones | 752.21 | 5.11 |
| M | Vimeiro limestones | 69.66 | 0.47 |
| N | Sandy deposits | 206.06 | 1.40 |
| Total | 14716.61 | 100.00 |

\* Percentage in relation to the total area of the municipality.

1. **Landforms**

The major landforms that result from Mendes (2010) model are described in table III and represented in figure 5. The code (1, 2, 3 and 4) is the output of the landforms classification. The landform description was given according to the prevalent slope gradient class.

Table III – Characteristics and areas of the major landforms.

*Quadro III – Características e áreas das formas de relevo principais.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Code | Symbol | Description | Prevalent slope gradient1 (%) | Area (ha) | Percentage\* (%) |
| 1 | Gs | Gently sloping | 0-5; 5-8 | 5020.67 | 34.12 |
| 2 | S | Sloping | 5-8; 8-12 | 5319.95 | 36.14 |
| 3 | Ss | Strongly sloping | 8-12; 12-16 | 3891.87 | 26.44 |
| 4 | Ms | Moderately steep | 16-25; >25 | 485.3 | 3.30 |
|  |  |  | Total | 14716.61 | 100.00 |

 \* Percentage in relation to the total area of the municipality.

1The underlined represents the prevalent slope gradient class

The landform class gently sloping, occupying 5020.67 ha, includes alluvial and colluvial areas as well as its surrounding areas; also, it includes the Cesareda tableland, where several colluvial/alluvial areas occur, and the area corresponding to the typhonic valley of “Bolhos” with sandy materials.

The landform class sloping, comprises the largest area of the municipality (5319.95 ha) and is related to the top areas corresponding to the ridgelines, where most of the settlement occurs.

The strongly sloping landform class is primarily associated with the work of the waterlines shaping the valleys; it is largely associated with the *Rio Grande* watershed and occupies about 3891.87 ha.

Finally, the landform class moderately steep has a smaller expression comprising 485.3 ha of the municipality area. This class describes the areas along the coastline in transition to the cliffs and the cliffs themselves, and also areas sectioned by geological faults, as *Cruz da Columbeira* and *Vila Verde faults* that slice up the I geological unit (Manuppella *et al*., 1999)*.*

1. **Soil-mapping units**

The distribution of resulting eight soil-mapping units is shown in the figure 6. The unit 1, mostly composed by *Regosols* and *Cambisols* (Table IV) is the largest soil-mapping unit in the Lourinhã municipality, occupying 9394.47 ha; small areas of *Leptosols* and eventually *Luvisols* and *Vertisols* may also occur. The cartographic information regarding these soil units suggests that the land use system has a strong influence on soil characteristics, as agropedic phases are frequent; in addition, mostly in the northern area of the municipality (Cesareda tableland), stony phases occur along with bedrock outcrops (see fig. 9). The soils in this unit, generally present a coarse to medium or even fine texture, although local variations may occur since the parent material varies from fine sandstones, clays and mudstones, to coarser sandstones and related rocks (IHERA, 1999); also, erosion and/or mass movements may also influence the soils of this unit, as it can be realized by some families’ designations resulting from colluvial deposition (IHERA, 1999) and by references regarding landslide risks (Cipriano, 2001).

The unit 2 covers 2758.79 ha and may include *Regosols*, *Calcisols* and *Leptosols* mostly developed on compact calcareous rocks; the *Regosols* and *Leptosols* may be qualified as calcic (*sensu* WRB, 2006) in some areas. The unit 3 (129.18 ha) including *Calcisols* and *Regosols* (mostly calcic) is largely developed over non-compact calcareous materials, and is mostly located in the northern of the municipality.

The unit 4 includes *Fluvisols* and occurs in alluvial areas (as designated in both geological and soil maps), whereas the unit 5 (associated with *Regosols* and *Fluvisols*) occurs in colluvial areas (as designated in the soil map), which are mostly designated as alluvial areas in the geological map; these soil-mapping units together comprise 1454.73 ha.

The unit 6 (37.15 ha) corresponds to *Arenosols* developed on sandy dune formations near the coast. Finally, the unit 7 (222.54 ha) includes *Arenosols*, *Regosols* and *Podzols* developed on the sandy formations, which filled the “Bolhos” typhonic valley.

Table IV – Constitution and areas of general soil mapping units.

*Quadro IV – Constituição e áreas das unidades cartográficas gerais de solos.*

|  |  |  |  |
| --- | --- | --- | --- |
| Soil-mapping units | Description | Area (ha) | Percentage\* (%) |
| 1 | RegosolsA, Cambisols. | 9394.47 | 63.84 |
| 2 | RegosolsB, Cambisols, LeptosolsB. | 2758.79 | 18.75 |
| 3 | Calcisols, RegosolsB. | 129.18 | 0.88 |
| 4 | Fluvisols. | 909.33 | 6.18 |
| 5 | Regosols, Fluvisols. | 545.40 | 3.71 |
| 6 | Arenosols. | 37.15 | 0.25 |
| 7 | Arenosols, Regosols, Podzols. | 222.54 | 1.51 |
| Social Area | Social Area. | 719.75 | 4.89 |
| Total | 14716.61 | 100.00 |

\* Percentage in relation to the total area of the municipality.

(a) - agropedic phase; (d) - shallow phase; (h) - hydromorphic phase; (i) - flooded phase; (p) - stony phase.

A May include small areas of *Leptosols* and eventually *Luvisols* and *Vertisols*.

B Part of them may be qualified as *calcic*.

1. **Land units**

From the intersection between the landforms and geological units, 33 basic physiographic units were delineated. As aforementioned, after framing the soil attribute and the presence of rock outcrops to the basic physiographic units, 33 land units were defined. These resulting land units were grouped in 11 general land units (table VI, fig. 7). Although most of these units are explained by its topographical position, the texture of the lithological materials and presence of rock outcrops was also used as criteria for their aggregation.

The land unit 1 represents the alluvial and colluvial areas mostly located at lower altitudes with gentle slopes, corresponding mainly to *Fluvisols* (and eventually *Regosols*), and comprising an area of 1473.82 ha; field observations indicate that this area is not intensively used for agriculture, possibly due to the occurrence of hydromorphic phases and flooding.

The unit 2 (27.36 ha) is associated with the beach area, with sandy materials and gentle slopes, whereas the land unit 3 is associated with *Arenosols* (over sand dunes) and occupies 36.9 ha.

The unit 4 (2528.13 ha) occurs in the areas with gentle slopes adjacent to the main alluvial areas that are located on the slope base, and soils mostly correspond to *Regosols* (in part calcic) and *Cambisols*; drainage limitations may occur in this unit since some hydromorphic phases exist.

The unit 5 (3360.37 ha) represents the slope areas bordering the alluvial and colluvial areas and presents great grain size variability, corresponding mostly to *Regosols*, *Cambisols* and *Leptosols*, at low extent; in this unit, erosion evidence was observed in some areas.

Table V – Attributes and areas of the land units.

*Quadro V – Atributos e áreas das unidades de terra.*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Land units | Composition | Geology | Landforms | Soils | Rocky outcrops | Area (ha) | Percentage\* (%) |
| 1 | aGs45 | a | Gs | 4, 5 | - | 1473.82 | 10.01 |
| 2 | AGs | A | Gs | - | - | 27.36 | 0.19 |
| 3 | DSs3 | D | Ss | 3 | - | 36.9 | 0.25 |
| 4 | GIGs12 | G, I | Gs | 1, 2 | - | 2528.13 | 17.18 |
| 5 | GISs1 | G, I | Ss | 1 | - | 3360.37 | 22.83 |
| 6 | GIS12 | G, I | S | 1, 2 | - | 5021.06 | 34.12 |
| 7 | IMs1 | I | Ms | 1 | - | 387.08 | 2.63 |
| 8 | FKGs123R | F, K | Gs | 1, 2, 3 | R | 1160.59 | 7.89 |
| 9 | FKIS23R | F, K, I | S | 2, 3 | R | 375.09 | 2.55 |
| 10 | EMs2R | E | Ms | 2 | R | 29.29 | 0.20 |
| 11 | NGs7 | N | Gs | 7 | - | 316.92 | 2.15 |
| Total | 14716.61 | 100.00 |

\* Percentage in relation to the total area of the municipality.

The land unit 6, where most of the settlement is concentrated, is the largest unit of the area (5021.06 ha) and describes the top sloping areas that include the ridgelines, *Regosols* and *Cambisols* being dominant, and, calcic *Regosols* and *Leptosols* occur at a lower extent; this unit, as mentioned for unit 5, presents great grain size variability associated with the parent materials corresponding to sandstones.

The unit 7 is mainly located along the coast representing the cliffs and areas sectioned by geological faults, and describes exceptional situations of moderately steep slopes, where *Regosols*, *Cambisols and Leptosols* may occur. It comprises an area of 387.08 ha.

The unit 8 (1160.59 ha) is located in the Cesareda tableland and represents the areas with gentle slopes where limestone formations occur and the presence of rock outcrops (not clear by the information reported in the soil map; see fig. 8 and table I) is a main landscape feature; soils mostly correspond to *Regosols* and *Cambisols*, but *Calcisols* and *calcic* *Regosols* may also occur in small areas.

The land units 9 and 10 are also located in the Cesareda tableland, have likewise a significant presence of rock outcrops. The unit 9 (375.09 ha), associated with *Calcic Regosols*, *Regosols*, *Cambisols*, *Calcisols* and *Leptosols*, describes the sloping areas, while the unit 10 (29.29 ha), associated with *Regosols* (partially calcic), *Cambisols* and *Leptosols* (partially calcic), describes areas with moderately steep slopes.

Finally, the land unit 11 (316.92 ha) corresponds to a gentle sloping landform and is associated with a mosaic of *Arenosols*, *Regosols* and *Podzols* developed on the sandy deposits located in the “Bolhos” typhonic valley.

IV. DISCUSSION

The applicability of the land unit concept involved a certain complexity given the type and quality of the available biophysical data for the area under study. Firstly, difficulties arose from the scale and legend heterogeneity of the geological map, and strong uncertainty may exist regarding the top of the lithological formations as a result of the sedimentary nature of geological formations; that is, a strong heterogeneity of soil parent material is expected. Secondly, the land unit delimitation process endorsed the recognition of strong deficiency of information on basic characteristics of soil units and therefore a limiting capacity to establish their classification; also, the rockiness (boulders and outcrops of bedrock material) was not revealed in the soil map and was confound by the stoniness (coarse fragments). Although the presence of bedrock outcrops (as a soil characteristic) is indicated in the Soil Capability Mapi, it did not overcome the deficiency (and inadequacy) of information provided by the Soil Map (1:25 000) (fig. 8, table I).

As the land unit delimitation methodology required a meticulous organization of the available data, it was possible to identify lacks of information and to improve the information presented in such maps. Therefore, the reorganization and improvement of information following the land unit assessment creates conditions for a deeper understanding of the land characteristics and qualities which may support the land capability and land suitability classification, allowing an adaptation of methodologies already used in another regions for the whole country (Agroconsultores and Coba, 1991; Agroconsultores and Geometral, 1995). That is, the land unit approach may be a useful tool to support land planning decisions (at different scales) and legislation (e.g. NAR) using identical criteria.

Our study indicates some similarity between the land units and the distribution of some soil capability classes and subclasses (figs 7 and 9). For example, the land unit 1 largely coincides with areas of the A soil capability class and some areas of the Bh and Bs subclasses (figs 7 and 9); also, Ds and ES subclasses largely coincides with the land units 8 and 9. However, our study also suggests that the landscape discrimination by the land unit approach is more detailed than that corresponding to the distribution of soil capabilityi classes and subclasses, as shown in the soil capability mapi (fig. 9). For example, the Ce soil capabilityi subclass comprising 6751.71 ha (about 45.9% of the total area; table V) corresponds to the largest area of the Lourinhã Municipality, and includes mostly areas of land units 4 and 6 and areas of land unit 5 (figs 7 and 9). This suggests that the land unit delimitation, following an improved framework of permanent biophysical features of the land, may facilitate a deeper land capability assessment (soil capabilityi classes). Similar considerations could be developed for the De soil capability subclass.

According to the Soil Capabilityi Handbook of Portugal (SROA, 1972), the subclass Ce corresponds to areas with severe limitations regarding erosion risks, with slopes up to 25% and limited effective soil depth (> 25 cm), and may be used for occasional cropping. Nevertheless, the areas of the subclass Ce (soil capability mapi) mostly correspond to those of land units 4, 6 and 5, where the dominant slope gradient classes are 0-5%, 5-8% and 8-12%, respectively (tables III and V). Although some soils in such subclass area may show an effective depth lower than 50 cm, most of them have an effective depth greater than 50 cm, and therefore could be considered in the Be capability subclass (slope up to 15% and effective soil depth > 35 cm); also, most areas of those land units could be included in the A2 land suitability established by Agroconsultores & Geometral (1995) for “The Entre Douro e Minho” for areas where slopes may range up to 15% and the effective soil depth is at least 50 cm. Indeed, in field observations it was observed that most of the Ce subclass areas are intensely used for agriculture, as opposed to what is considered for the Ce soil capabilityi subclass (SROA, 1972). As long as agricultural management practices are implemented to control the erosion processes, such areas may not show biophysical constraints to be classified as Ce. Similar considerations could be outlined for most of the areas classified in De soil capabilityi subclass (figs 7 and 9).

Table VI – Soil capability classes and subclasses in the Soil Capability Mapi corresponding to the Lourinhã municipality.

Quadro VI – Classes e subclasses de capacidade de uso na Carta de Capacidade e Uso do Solo do município de Lourinhã.

|  |  |  |
| --- | --- | --- |
| Soil capabilityi classes and subclasses | Area (ha) | Percentage\* (%) |
| A | 881.92 | 6.00 |
| Social Area | 719.75 | 4.89 |
| Be | 558.25 | 3.79 |
| Bh | 162.11 | 1.10 |
| Bs | 517.88 | 3.52 |
| Ce | 6751.71 | 45.88 |
| Ch | 25.55 | 0.17 |
| Cs | 419.98 | 2.85 |
| De | 3071.12 | 20.87 |
| Ds | 598.14 | 4.06 |
| Ee | 292.15 | 1.99 |
| Es | 718.05 | 4.88 |
| Total | 14716.61 | 100.00 |

\* Percentage in relation to the total area of the municipality.

According to the soil capability mapi, only 14,41% of the area (6% of class A and 8,41% of class B) is well suited for intensive cropping and grazing activities; however, most of this land is not used for intensive cropping, which may be associated with flooding risks and drainage limitations in some areas, as suggested by the hydromorphic and flooding phases reported in the Soil Map (table I). Therefore, considering that the subclass Ch only occupy 0,17% of the municipality area (see table VI), only 14,58% of the area would be, in principle, considered within the National Agricultural Reserve (NAR), according to the Ministerial Order nº 73/2009, 31st March). As aforementioned, large areas of the Lourinhã municipality, especially those corresponding to land units 4, 6 and 5, could be positioned in the B capability class (mostly Be subclass), or in A2 suitability class (moderate suitability for agricultural crops) established for The Entre-Douro e Minho region (Agroconsultores & Geometral, 19995). In such a case, following the same Ministerial Order nº 73/2009, 31st March), recognizing that “are part of the NAR the land units that present a high or moderate suitability for agriculture”, the NAR area could reach a high proportion of the municipality area, as the proportion of those land units reach about 74% (see table V). This large discrepancy is clearly associated with the fact that the soil capabilityi units were not delimitated within a framework of land units, being most of the area considered to have steep slopes (Ce subclass). In short, the land unit delimitation may allow an improved framework of the soil capabilityi classes and subclasses as well as an improved outline to identify and delimitate NAR areas.

Land physical limitations in the Lourinhã municipality are mostly associated with erosion hazard, rockiness, drainage/flooding and climate. Meanwhile, erosion risk may be the largest hazard, as about 72.5% (see Table VI) of the area is included in erosion subclasses of different classes. Although the apparent contradiction with aforementioned considerations regarding land capability classification, it should be emphasized that erosion (sheet and rill erosion) is common and pronounced even in areas with gentle slopes (as land unit 6 with a prevalent slope gradient between 5-8%), as recognized by field observations (fig. 10).

Besides the soil erodibility and the slope angle, soil erosion is also associated with the removal of hedgerows, stonewalls and other fences (delimitating land parcels) for easier crop management, resulting in an increment of slope length and uniformity, and with reduction of soil protection (fig. 11). That is, despite the slope and soil erodibility effects, erosion risks in Lourinhã municipality are strongly related to the great changes in the land use system and the absence of required conservation measures. Also, mass movements (land slip, slumping, soil creeping) risks should be also taken into account for land capability purposes, as Cipriano (2001) reported that “the nature of the clay soils may be the cause of the population’s decay, as prolonged rains create landslides that drag everything with it”.

Physical limitations related to rockiness are mostly associated with the limestone formations (land units 8 and 9) in the Cesareda tableland (Ribeiro, 1940; see fig. 8), and may have strong impact on trafficability. Likewise, limitations regarding flooding and drainage must be considered, especially in those areas that apparently did not presented constrains for agricultural purposes (as the soil capability mapi states). Despite drought associated with uneven rainfall distribution, limitations regarding climate may be also strongly associated with the effect of wind in exposed areas, as is suggested by the landscape compartment in areas close to the coast (fig. 11), which in turn may contribute to minimize soil erosion. From the present study, becomes evident that the land unit delimitation is an essential tool to improve land limitations assessment and support land capability and suitability classifications.

V. CONCLUSIONS

From the present study, it becomes evident that land unit mapping can potentially provide greater information than the soil capability mapi. The land unit mapping is an essential tool to resort to in landscape planning, by assisting data collection and by improving the information available in soil and soil capability mapsi, as it may aid in the reorganization, requalification and homogenization of available information. Even in areas with great complexity, as the area under study, land unit mapping allows to outline unified methodologies, with identical criteria, to assess the capability and suitability of the land. The land unit mapping may enable to develop a unified system to more accurately delineate management tools (such as the NAR) for the whole country, meeting the general requirements of the existing legislation. Thereby it is an essential support for the landscape planning decisions. As land unit mapping is a top-down process that requires a careful data analysis, further research should be developed in larger areas to clarify its potential benefits regarding land planning in Portugal.

ACKNOWLEDGEMENTS

Authors gratefully acknowledge Isabel Roussado for helping handling data and Paulo Marques for fieldwork assistance. The support of Prof. Ana Carla Madeira for English style improvement is also acknowledged.

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4. The terms “soil capability map” and “soil capability classification” are a translation of the Portuguese terms “*carta de capacidade de uso do solo*” and “*classificação da capacidade de uso do solo*”, which approximately correspond to the land capability classification (Klingebiel and Montgomery, 1961). Although the aim was to develop a classification based on the land capability classification (by the United States Soil Conservation Service), the soil capability classification (in Portugal) did not consider the climate and was based on less detailed soil information as compared to that used in the USA (SROA, 1972). [↑](#endnote-ref-1)
5. This term is used to translate the Portuguese term “carta de ocupação e uso do solo”. [↑](#endnote-ref-2)
6. The alluvial areas in the geological map do not coincide with those in the soil map. Firstly, because the geological map and the soil map have different scales. Secondly, some alluvial areas of the geological map are colluvial areas according to the soil map. Hence it was preferable to use the alluvial and colluvial areas of the soil map for the land unit delimitation. [↑](#endnote-ref-3)