Methodology to standardize soil mapping in Portugal

Metodologia para uniformizar a cartografia de solos em Portugal

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A B S T R A C T

Updated and harmonized soil information is essential for sustainable land use and the conservation of natural resources. In Portugal, however, soil maps vary significantly in scale, classification systems, and mapping and analytical methodologies. Standardizing these maps at a scale of 1:100,000 in the WRB system, utilizing digital tools and existing soil information, is crucial. In three pilot areas south of the Tagus River, factors influencing soil characteristics were categorized as follows: (i) lithology, in terms of rock origin, silica/carbonate content, and degree of consolidation; (ii) relief, considering slope, hypsometry, curvature, and landforms; and (iii) climate, based on thermal regime. By intersecting this information with the proportion of rocky outcrops, homogeneous zones were delineated, and soil-mapping units were subsequently defined using SROA/CNROA information (1:25,000). This process identified 23 lithological groupings, five relief classes, and seven climatic classes, resulting in 125 homogeneous zones with a minimum area of 30 ha. This standardized soil information aligns with the requirements of the EU INSPIRE directive, supporting the development of a harmonized land capability map for mainland Portugal.

Keywords: digital soil mapping, homogeneous zones, SROA/CNROA, WRB, soil information legacy.

R E S U M O

Informação atualizada e harmonizada sobre o recurso solo é essencial para o uso sustentável da terra e a conservação dos recursos naturais. Porém, em Portugal, a cartografia de solos é heterogénea quanto à escala, sistema de classificação e metodologias cartográfica e analítica. É crucial uniformizá-la, na escala 1:100000 e no sistema WRB, usando ferramentas digitais e o legado de informação existente. Em três áreas piloto, a sul do rio Tejo, categorizaram-se os fatores determinantes das caraterísticas dos solos: (i) litologia, quanto à origem das rochas, teor em sílica/carbonatos e grau de consolidação; (ii) relevo, considerando o declive, a hipsometria, a curvatura e as formas de relevo; e (iii) clima, quanto ao regime térmico. A interseção desta informação e da proporção de afloramentos rochosos permitiu delimitar "zonas homogéneas" e, a partir destas, unidades cartográficas de solos, utilizando a informação SROA/CNROA (1:25000). Obtiveram-se 23 agrupamentos litológicos, cinco classes de relevo e sete classes climáticas. Definiram-se 125 zonas homogéneas, com área mínima de 30 ha. Tal permite unificar a informação cartográfica de solos em Portugal Continental e enquadrá-la nos requisitos da diretiva INSPIRE da UE, bem como estabelecer a carta de aptidão das terras harmonizada para todo esse território.

Palavras-chave: cartografia digital de solos, zonas homogéneas, SROA/CNROA, WRB, legado de informação de solos.

INTRODUCTION

The sustainable use of land and the conservation of natural resources should be based on updated and harmonized information about the resource soil (Carré *et al*., 2017). Still today, in Portugal, soil maps are very heterogeneous in terms of scale (about two-thirds of the country area is mapped at scale 1:25000, while the remaining third is mapped at scale 1:100000), classification system (SROA classification for the former, and FAO/WRB for the later), and mapping and analytical methodologies.

The map information prepared at scale 1:100000 corresponds to the soil and land capability maps (*Cartas de Solos e de Aptidão da Terra*) of three northern regions: *Trás-os-Montes e Alto Douro* (Agroconsultores & Coba, 1991), *Entre Douro e Minho* (Agroconsultores & Geometral, 1995) and *Zona Interior Centro* (Agroconsultores & Geometral, 2004), all of them available in digital format (DGADR--SNIS, 2022). The elaboration of these maps was based on the prior delimitation of "homogeneous zones" in terms of their ecological context – essential to foresee the type and some of the soil characteristics –, having been considered as classification systems, respectively, the Legend of the Soil Map of the World (FAO, 1987), the Legend of the World Soil Map, revised version (FAO/UNESCO, 1988) and the first version of the World Reference Base for Soil Resources, WRB (IUSS Working Group WRB, 1998). Each soil-mapping unit thus fits into an ecologically homogeneous zone, leading to a "landscape unit", that is, a fraction of the landscape homogeneous in terms of geology, relief, climate, soil, vegetation and land use (Zonnveld, 1995; Blasi *et al*., 2008).

This mapping approach made it possible to simultaneously generate information on the "characteristics" and "qualities of the land", essential elements for the "classification of land capability" (sensu FAO, 2007) for common uses, which is considered in the legislative instrument that delimits the National Agricultural Reserve (RAN) in the mentioned regions (Decree-Law no. 73/2009, of March 31st, with changes introduced by Decree--Law no. 199/2015, of September 16th).

In the soil mapping of the regions of *Algarve, Alentejo, Área Metropolitana de Lisboa* and *Zona Litoral Centro*, available in digital format at scale 1:25000 (SROA, 1973), the methodologies and classification systems differ from those previously considered. The soil mapping of these regions essentially consisted of the mere delimitation of soil-mapping units, considering the Portuguese soil classification (*Classificação dos Solos de Portugal*) (SROA, 1973), with no homogeneous zones having been previously delimited. The classification system used has not been updated and, more importantly, the morphological and analytical characterization of most taxonomic units (*Famílias*) is unknown (IDRHa & SPCS, 2005). Moreover, the location of the reference profiles that were adequately characterized is unknown.

For these same regions, a land use capacity map (*Carta de Capacidade de Uso do Solo*) was published (SROA, 1972). But this map does not exactly correspond to the Land Use Capability elaborated in the USA (Klingebiel & Montgomery, 1961), essentially for not considering climatic elements. This map is also included in the legislative instrument that currently delimits the RAN (Decree-Law no. 73/2009), to be applied only in the regions of *Algarve, Alentejo, Área Metropolitana de Lisboa* and *Zona Litoral Centro*. In other words, the RAN on the scale of the continental territory is delimited by two mapping systems that have not been subject to any harmonization or compatibility.

In this context, it is essential to create the methodologies that make it possible to standardize the soil mapping of Continental Portugal, at a 1:100000 scale, using a single and updated classification system (of global interest), to provide a harmonized map product applicable to this entire territory. This will facilitate the communication and approaches to the study of soil, the harmonization of land capability classification as well as the support for policies and measures that promote sustainable land use. These methodologies were tested and developed in three pilot areas, located south of the Tagus River, referred to as: Portalegre (municipalities of Alter do Chão, Crato, Fronteira, Marvão, Monforte, Nisa, Portalegre), Coruche (Almeirim, Benavente, Coruche, Montijo, Mora and Salvaterra de Magos) and Beja (Aljustrel, Alvito, Beja, Cuba, Ferreira do Alentejo and Vidigueira).

MATERIAL AND METHODS

The reformulation of soil mapping (and later of land use capability mapping), in the regions of *Algarve, Alentejo, Área Metropolitana de Lisboa* and *Zona Litoral Centro*, necessarily implies the systematization, reorganization and harmonization of all available information on the biophysical environment and on soils, which involves multiple activities, distributed over several phases (Figure 1).

To delimit the lithological units, sheets 6, 7 and 8 of the Portuguese geological map in digital format (vector) at scale 1:200000, provided by the National Laboratory of Energy and Geology (LNEG), were considered. However, given the excessive scope of the designations referring to sedimentary formations, it was decided to delimit the lithological units of these areas based on the designations used for the Family taxonomic level of SROA/CNROA soil map (1:25000). Lithological groupings

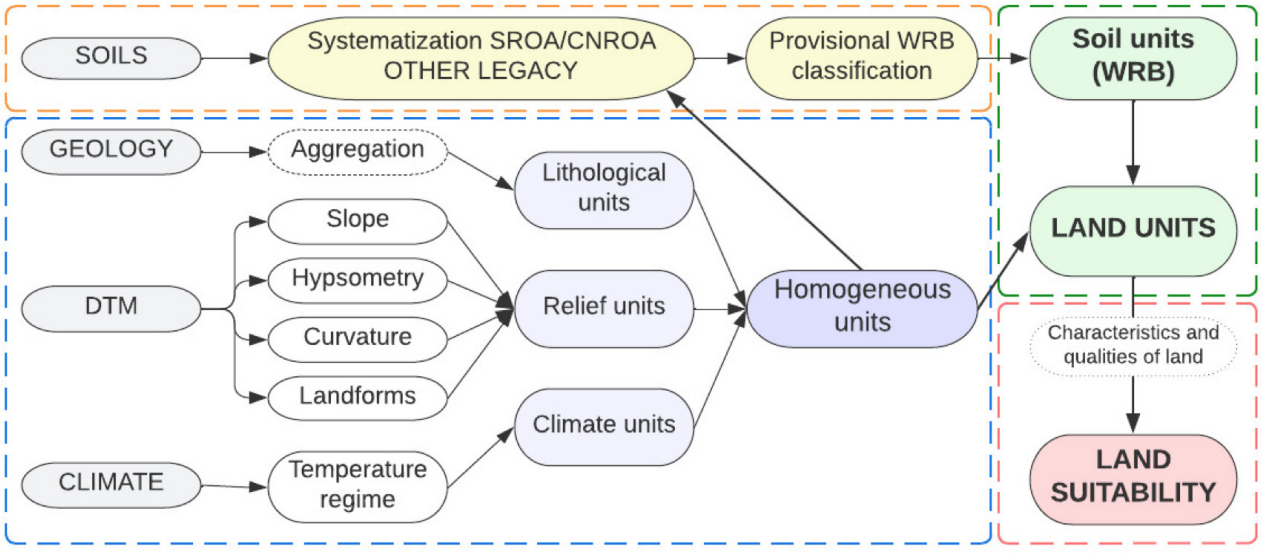

Figure 1 - Workflow of the project: (blue) first phase – delimitation of homogeneous units; (yellow) second phase – definition of provisional soil-mapping units; (green) third phase – definition of definitive soil-mapping units and land units; (red) fourth phase – creation of the land suitability map.

First phase

The activities began with the systematization and delimitation of the so-called "homogeneous zones" (or "homogeneous units") in terms of lithology, relief and climate, allowing us to preview some soil characteristics (for example, texture). The systematization of biophysical information (mapping of relief units or landforms) was organized in a digital format based on a Digital Terrain Model (or DTM) with a resolution of 25x25 m (EROS, 2017). Landforms were derived based on Hammond's (1954) classification model, following the procedures proposed by Morgan & Lesh (2005) which were later applied to mainland Portugal by Mendes (2010). Thus, the slope, the unevenness and the concavity/convexity of the terrain surface were considered.

were defined based on the type of rock (igneous, metamorphic or sedimentary), its degree of consolidation and its silica and carbonate content.

Regarding the delimitation of climatic units, the source data was the normalized thermal data series for the period 1981-2010, provided by the Portuguese Institute for Sea and Atmosphere (IPMA) in digital format (raster, of 1 km resolution). Temperature variables considered were the average annual temperature, the average temperature of the hottest month and the average temperature of the coldest month (all in °C). Finally, the level of occurrence of rocky outcrops was obtained from the SROA/CNROA soil map at scale 1:25000 in digital (vector) format.

For each of the four previous layers of information, a minimum area of the respective polygons was stipulated – 25 ha for lithology, climate and rocky outcrops and 250 ha for relief –, so that those that did not meet this requirement were dissolved in the adjacent ones (*eliminate*), based on a previously established similarity rule. Then, all layers were intersected to generate the provisional homogeneous zones.

Finally, overlaying the SROA/CNROA soil map (1:25000), some of those homogeneous zones were redefined. For example, regarding the homogeneous zone corresponding to alluvium, it was observed that in some areas soils without hydromorphism or salinity (Fluvisols) predominated, in others hydromorphic soils (Gleisols) and/or soil with moderate salinity (Fluvisols (Salic)) and in others soils of high salinity (Solonchaks) were dominant; therefore, this homogeneous zone was manually divided into three different zones, as they must differ considerably from each other in terms of characteristics and management requirements. Each definitive homogeneous zone has a minimum area of 30 ha, provided it was considered the minimum representative area at scale 1:100000.

Second phase

At this stage (in progress) the provisional soil-mapping units are defined. Thus, it is necessary to: (i) systematize, simplify and harmonize the legend of the Portuguese Soil Classification (IDRHa & SPCS, 2005), essential for the due simplification and map harmonization (Madeira *et al*., 2021); (ii) evaluate the proportion of soil units from the Portuguese Soil Classification legend (SROA, 1973; IHERA, 1999) that occur in each homogeneous zone; and (iii) convert the designations of previous soil units into the WRB system, for later identification of which main groups of soils are "dominant", "codominant", "associated" or "sporadic", depending on whether the proportion of occupied area in the homogeneous zone is ≥50%, [25%-50%[, [5-25%[, [1%-5%[, respectively (IUSS Working Group WRB, 2022).

Third and fourth phases

Once the provisional soil-mapping units are defined in each homogeneous zone, their spatial distribution and definitive classification are established, in accordance with the WRB system rules (IUSS Working Group WRB, 2022), based on the legacy of available and most important information (Carré *et al*., 2017), to define the definitive soil-mapping units and, therefore, the land units. Next, the characteristics and qualities of each land unit are defined and typified, in accordance with the methodology considered for other regions of mainland Portugal (Agroconsultores & Coba, 1991; Agroconsultores & Geometral, 1995, 2004). Finally, the suitability of different land units is classified for common agricultural and forestry purposes (Agroconsultores & Geometral, 2004).

RESULTS

In the three pilot areas mentioned, the factors determining soil characteristics (lithology, relief and climate) were categorized, obtaining 23 lithological groupings, five relief classes and seven climatic classes.

Lithological groupings include: "granites and related rocks" (g), "diorites, quartzdiorites and related rocks" (d), "mafic rocks" (b), "ultramafic rocks" (u), "schists and related rocks" (x), "green schists" (xv), "quartzites, schists and related rocks" (q), "marbles" (m), "gneisses and related rocks" (n), "intermediate and mafic metamorphic rocks" (t), "sandstones" (r), "conglomerates" (l), "compact limestones" (cc), "non-compact limestones" (c), "marls and related materials" (mg), "sands" (a), " alluvium" (f), "colluvium and slope deposits" (v), "unconsolidated or poorly consolidated sandy materials" (s), "argillaceous materials" (k), "unconsolidated medium-textured materials" (sk), "sandy materials on sandstones and/or clayey materials" (sr), "gravelly and sandy and/or clayey materials" (cs). In Coruche pilot area, there are almost exclusively sedimentary formations; in Portalegre, magmatic and metamorphic formations; and in Beja, all three types of formations are well represented.

Regarding relief, the following classes were defined: "plains" (p), "rolling hills" (s), "mountains" (o), "steep mountains" (m), and "very steep mountains" (e). In Beja pilot area and especially in Coruche, the "p" and "s" classes are more common, while in Portalegre, the "o" and "m" classes dominate.

The following climatic zones were defined: "Sub--Atlantic Temperate Land" (T1), "Continental Temperate Land" (T2), "Atlantic Hot Land (Q1)"; "Continental Hot Land" (Q2), "Coastal Hot Land" (QL), "Coastal Land" (L), "Temperate Subatlantic Transition Land" (T3). The Coruche pilot area is included in the "QL" and "Q2" classes, Beja only in "Q2" and Portalegre essentially in "Q2", but also "T2" (higher elevation areas).

63 in Coruche and 72 in Portalegre. In all three test areas, 125 definitive homogeneous zones were obtained.

From here, it is possible to define the soil-mapping units (provisional and then definitive) and the land units. In turn, the assessment of the characteristics and qualities of each land unit will allow to obtain the land suitability map harmonized for the entire

Figure 2 - Definitive homogeneous units of Beja test area. Each colour corresponds to a specific homogeneous unit, which is defined by a combination of different symbols (specified in the text): climate, lithological material, relief and rocky outcrops abundance (if not "rO").

Four classes of rocky outcrops were also considered, depending on their proportion in relation to the soil in the previously delimited areas: "r_0" [0-20%[, "r_1" [20%-50%[, "r_2" [50%-70%[and "r_3" [70%-100%].

In the QGIS software, the intersection of the four layers of information mentioned made it possible to delimit 72 homogeneous zones in Beja (Figure 2), territory of Mainland Portugal.

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