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Delimitation of Soil Districts in mainland Portugal

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Resumo

A Diretiva de Monitorização do Solo da UE promove a gestão sustentável do solo nos Estados-Membros, propondo Unidades de Solo (US) dentro de Distritos de Solo para monitorização/governação eficazes. A heterogeneidade do solo é abordada com técnicas avançadas, incluindo machine learning, geoestatística e SIG. A metodologia avalia a qualidade do solo utilizando dados climatológicos, do uso/tipo do solo e propriedades do solo, para delinear US. A harmonização dos sistemas de monitorização e a criação de um observatório do solo aumentam a fiabilidade dos dados. O projeto nacional, financiado pela FCT, destaca o envolvimento das partes interessadas e a sustentabilidade agrícola.

Palavras-chave: Distritos de Solo; Unidades de Solo; Modelação; SIG.

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Abstract

The EU Soil Monitoring Directive promotes sustainable soil management in Member States, proposing Soil Units (SU) within designated Soil Districts for effective monitoring and governance. Addressing soil and land-use heterogeneity requires advanced statistical techniques, including machine learning, geostatistics, and GIS. The methodology assesses soil quality using climatological, land-use, soil properties, and lithological data to map multi-purpose SU. Harmonising monitoring systems nationally and creating a comprehensive soil observatory improve data reliability and decision-making. The national soil monitoring project, funded by FCT, emphasises stakeholder engagement through workshops, participatory planning, and training to support sustainable soil management and agriculture sustainability within the EU.

Keywords: Soil Districts; Soil Units; Modeling; GIS.

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Introduction

The European Union (EU) Soil Monitoring Directive is a key legislative instrument designed to promote sustainable soil management practices in the member states. The directive outlines the establishment of Soil Units (SU) within designated Soil Districts, which are fundamental for soil monitoring and governance. The parameters used are the responsibility of each Member State, although the need to reach a consensus that encompasses at least a few basic parameters is emphasized.

However, the heterogeneous nature of soil typology (WRB 2014) and land use across the member states presents significant challenges in effectively delineating these units. Addressing this complexity requires sophisticated methodologies and interdisciplinary collaboration.

Recent advancements in statistical techniques and modeling have provided new opportunities for the precise delineation of SU. Machine learning (ML) algorithms, geostatistical analyses, and geographic information systems (GIS) have emerged as valuable tools in this context. Various numerical approaches, including fuzzy clustering and principal component analysis (PCA), have been proposed to delineate SU, leveraging various environmental and soil data sources.

However, achieving multi-use SU remains challenging due to the intricate interactions between soil properties. A dynamic methodology that integrates soil quality assessment is proposed in response to these challenges. A central aspect of the proposed methodology is using ML algorithms and integrating diverse datasets. The primary inputs include climatic data (e.g., maximum and minimum precipitation and maximum and minimum temperature), land use maps, soil element data (e.g., organic carbon, phosphorus, zinc, magnesium, among others), and lithological information. Tasks focused on lithological mapping, climate response units, and soil unit clustering are integral components of the proposed framework, aiming to develop a robust methodology for SU delineation.

The future harmonisation of monitoring systems at the national level is emphasised, along with the establishment of a comprehensive soil observatory. With the creation of a national soil observatory, it will be possible to hold all the important information on soils in one place, making it easier to share, use and add new information. These initiatives enhance data reliability and facilitate soil health assessment, contributing to evidence-based decision-making. Moreover, the project highlights the importance of stakeholder participation and collaboration, especially among rural development agents.

The project aims to support evidence-based decision-making at the agricultural exploitation level and inform rural development policies by creating an information system to record the results of soil analysis and cultural practices. Ultimately, the national soil monitoring system project (MLSOIL) seeks to advance sustainable soil management practices through interdisciplinary collaboration and innovative methodologies tailored to the diverse contexts within the EU. The EU aims to safeguard soil resources for future generations through concerted efforts while promoting agricultural sustainability and rural development.

Recent Developments in Soil Units

The European Union Soil Monitoring Directive (Direção-Geral do Ambiente, 2023) provides for the definition of soil districts (administrative units) and associated soil units (monitoring units with a minimum level of harmonisation, SU) as areas for soil monitoring and the implementation of sustainable soil management. Adopting distinct soil nomenclature at the national level, combined with a wide diversity of land cover and land use, makes it very difficult to establish and define these boundaries. It is important to emphasise that these soil units should constitute the basic units of governance for soil management and adopt

measures to meet the requirements in the proposed directive, especially regarding soil health monitoring and assessment.

The uniformity of soil properties within the SU is crucial for sustainable soil management, long-term productivity, and the prevention of environmental issues. Studying spatial variation in soil fertility status is essential for sustainable activities (Taghizadeh-Mehrjardi et al., 2020). In recent decades, considerable advancements in statistical techniques and modelling approaches have allowed for the precise delineation of agricultural zones using new methods such as ML, geographic information systems (GIS), remote sensing, and geostatistics. Several numerical approaches have been proposed for SU delineation based on soil properties, including fuzzy k-means cluster analysis (Zeraatpisheh et al., 2020), fuzzy c-means clustering algorithm, and PCA. However, selecting the appropriate technique/approach depends on the purposes for which the SU are being delineated. Previous studies have documented the application of SU delineation for agricultural systems, using various environmental and soil data sources, such as pedo-geomorphological factors, soil nutrients, and intrinsic soil properties (e.g., electrical conductivity, pH, particle size distribution, soil organic matter, nitrogen, phosphorus, and potassium) (Zeraatpisheh et al., 2020).

The main reason for developing SU is to delineate homogeneous areasHowever, some statistical tests commonly used to determine SUs, such as one-way analysis of variance, only consider individual soil properties. Kerry et al. (2021) investigated whether the SU identified using remote sensing, topographic, and yield data were optimal for managing multiple nutrients or soil properties simultaneously and found that although the units could be used to manage more than one property, they were not truly multi-use and could not be used to manage all or most properties at once.

Therefore, a dynamic delineation methodology is needed to assess the interactions of soil and multiple properties in combination. Soil quality assessment can be considered effective in representing the quality and sustainability of ecosystems. It considers the interaction of different variables (e.g., soil properties) and is based on other references and thresholds to classify the soil into various soil quality levels. Soil quality assessment could be used to evaluate the homogeneity of the delineated SUs.

Regarding the homogeneity of the SUs within soil districts, the first version of the Soil Monitoring Directive (Direção-Geral do Ambiente, 2023) suggests the use of the geostatistical Bethel algorithm to deal with (few) soil properties, retrieved from Copernicus platform, and ensure interactions of soil properties with a variation coefficient of less than 5% within each SU.

Methodology

Soil districts should constitute the basic units of soil management and decision-making to comply with the requirements in this Directive, especially regarding soil health monitoring and assessment. The number, geographic extent, and boundaries of the soil districts for each Member State should be determined to facilitate the implementation of the EU Regulation. The minimum number of soil districts for each Member State should correspond to the number of NUTS I territorial units. Member States must designate a competent authority for each soil district to ensure proper soil governance.

All actions will be carried out in close coordination with the European Commission (EC), the Joint Research Centre (JRC), the Portuguese Soil Partnership (PPS), and, in some cases, with farmers and foresters – citizen science. An important feature of these tasks is related to concepts. Soil quality can transform soil science from a neutral science in terms of value into a value system, and soil quality can even be referred to as promoting ideas of politically correct soil. Furthermore, there are also different definitions and, consequently, different understandings of structural concepts such as Soil Quality, Soil Health, Ecosystem Services (of the Soil), or Soil Functions that need to be addressed

(Weninger et al., 2024).

When establishing the geographic extent of the homogeneous soil unit grid, Member States may take into account existing administrative units and should aim for homogeneity within each soil district about the following parameters: i) soil type as defined in the World Reference Base for Soil Resources; ii) climatic conditions; iii) environmental zone as described in the Alterra Report; and iv) land use or land cover as used in the Land Use/Cover Area frame Statistical Survey (LUCAS) (or similar).

Regarding i), we will provide a 1:100,000 lithological map for mainland Portugal. We also can access better climatic data (ii) than the suggested WorldClim dataset. These data have a spatial resolution of 1 km² and correspond to a somewhat outdated climatological normal. We will use the 1982-2010 climatological normal from the Portuguese Institute for Sea and Atmosphere (already acquired). Considering that we also have a detailed Official Land Use and Cover Map (1:25,000; Carta de Uso e Ocupação do Solo (COS) 2018) (iv), it will be possible to process more detailed information than those suggested in (iii), both geometrically and/or semantically. Therefore, we will develop Homogeneous Climate Response Units (HCRUs).

This data will allow us to create the geographic grid of soil units, which will be the basis for all modelling processes. The second phase will cover the clustering process of the geographic grid of homogeneous soil units. This will be done using soil property data provided by the EU (e.g., Copernicus), namely phosphorus content, total nitrogen content, granulometric distribution (clay, silt, sand), coarse fragments, pH, organic carbon (OC), carbonate content, extractable potassium content, and cation exchange capacity.

Additionally, there are also data on pollutants. For example, copper (Cu), mercury (Hg), and zinc distribution in surface soils. Cu, for example, is correlated with soil properties (pH, texture, OC), climate, and lithology. Several clustering methods will be applied and evaluated after dealing with this data variability and multicollinearity (Zeraatpisheh et al., 2020). The most positive result of all of the tests carried out so far were those where the parameters used were the NUTS II, the Corine Land Cover, the soil bulk density at a depth of 0 to 10 cm, the copper concentration, the nitrogen content, the organic carbon content, the phosphorus content and the soil pH, which resulted in 14 soil units all over mainland Portugal.

Establishing a harmonised national monitoring system, along with the systematisation and standardisation of indicators for the European Soil Strategy, is also necessary. This contributes to effectively applying, monitoring, and evaluating management measures and soil policies at different levels, from national to regional and local. Thus, several methods will be tested and compared (Lawrence et al., 2020).

Conclusion

To comply with the obligations related to soil health monitoring (for collecting soil samples), the competent authorities in the Member States may need to request landowners to grant them access to their properties following the applicable national rules and procedures. Member States may also require landowners to implement measures to manage the soil sustainably. Data from soil analysis periodically carried out on agricultural plots, in integrated and organic production modes, that benefit from support under the Common Agricultural Policy, could contribute to monitoring the soil health status in the country's agricultural areas, i.e., the soil observatory.

To achieve this, it will be necessary to ensure the reliability and harmonisation of sample collection procedures, analytical methods, and data collection in a national information system. This data, combined with information about cultural practices in each plot (>= 100 m²) which farmers are required to record, would allow for the assessment of the impact of these practices on soil health.

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