

Monitoring the impacts on ecosystem services through different soil management practices to inform sustainable land-use and land-cover policies

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Executive summary

The MonLand project aimed to produce integrated and spatially explicit information on the status of soils and ecosystem services in mainland Portugal, in order to support the design, implementation, and monitoring of public policies in the fields of environment, agriculture, and spatial planning. In a context of increasing pressure on natural resources, the project responds to the need for robust tools capable of simultaneously assessing the biophysical quality of the territory and the benefits it provides to society. The study developed a Soil Quality Index (SQI), based on the integration of 18 physical, chemical, and biological indicators, enabling the characterization of soil conditions at the national scale and the identification of spatial patterns of degradation and conservation. In addition, four ecosystem services were assessed: two regulating services, habitat quality maintenance and erosion control through sediment retention, and two provisioning services, agricultural production and annual water yield. The results reveal pronounced territorial contrasts associated with land use and land cover, climatic conditions, and regional biophysical characteristics. Areas subject to higher anthropogenic pressure tend to exhibit lower soil quality values and a reduced capacity to deliver certain regulating services, whereas territories with more continuous vegetation cover play a key role in soil protection, biodiversity conservation, and the regulation of hydrological cycles. The integrated approach adopted in the project allows for the identification of priority areas for intervention, supports the alignment of agricultural, environmental, and spatial planning policies, and contributes to harmonising national strategies with the Common Agricultural Policy, the Water Framework Directive, and European soil protection objectives. MonLand thus provides a solid technical basis for more sustainable and informed land management.

Recommendations

- Integrate the Soil Quality Index and ecosystem services into the definition of territorial and agricultural planning priorities;
- Target agri-environmental measures and soil conservation actions towards areas identified as most vulnerable to degradation;
- Strengthen the protection and active management of areas with high regulatory capacity, particularly in sediment retention and habitat maintenance;
- Use the project results as a basis for the continuous monitoring of soils and ecosystem services within national and European policy frameworks.

Target audience of the policy brief

Portuguese Environment Agency and the Institute for Nature Conservation and Forests.

Introduction and Problem Statement

Soil is a strategic resource that is essential for food production, the regulation of natural cycles, biodiversity conservation, and the resilience of territories to climate change (Kopittke et al., 2019). In mainland Portugal, soils are subject to multiple pressures resulting from agricultural intensification, urban expansion, land take, and increasing climate variability. These factors contribute to degradation processes such as erosion, loss of organic matter, compaction, and a decline in the capacity to deliver ecosystem services (Ferreira et al., 2022; Právělie et al., 2021). Despite its importance, soil remains insufficiently integrated into planning instruments and sectoral public policies (Terribile et al., 2024).

The lack of integrated, comparable, and spatially explicit information hampers the identification of critical areas and the definition of effective measures for the prevention and mitigation of degradation. Moreover, the

isolated assessment of biophysical components fails to capture the complexity of interactions between soil condition, land use, and the benefits provided to society.

In this context, it is essential to have tools that allow for the joint assessment of soil quality and the associated ecosystem services, thereby supporting a more integrated approach to land management. The articulation between soil quality indicators and regulating and provisioning services is particularly relevant in addressing the challenges posed by European policies, namely the Common Agricultural Policy, the Water Framework Directive, and the objectives related to soil and biodiversity protection (Efthimiou, 2025; Martinho et al., 2024). It is within this framework that the MonLand project is situated, aiming to strengthen the knowledge base required for more sustainable and informed land management.

Analysis / Key Findings

The analysis of the MonLand project results is based on a set of indicators whose selection and scaling were supported by the scientific literature and validated through a participatory process involving institutional stakeholders and experts. Within the scope of the project, a participatory workshop was held with representatives from public administration and academia, during which the indicators of the Soil Quality Index (SQI) were discussed and validated, and the ecosystem services to be assessed were prioritised. This process strengthened the conceptual validity and reliability of the indicators used, ensuring their suitability for decision-making support and spatial planning, as well as their relevance within the context of national and European environmental sustainability strategies. The Soil Quality Index, constructed from 18 physical, chemical, and biological indicators, reveals high spatial variability across mainland Portugal. Index values range from low to high quality classes, with a clear concentration of higher values in areas with greater continuous vegetation cover and lower land-use intensity, such as forest and agro-silvo-pastoral systems. Spatial analysis demonstrates a statistically significant positive autocorrelation, indicating

that municipalities with high SQI values tend to cluster, as do areas with lower soil quality (Figure 1), highlighting the influence of biophysical factors and land management practices.

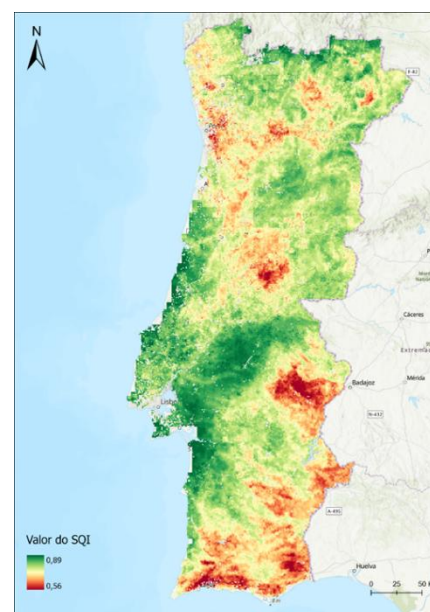


Figure 1 – Soil Quality Index

With regard to regulating services, Habitat Quality shows higher values in inland territories and in less fragmented areas, while coastal and urbanised areas exhibit higher levels of degradation. Hot spot analysis confirms the existence of well-defined spatial patterns, with direct implications for biodiversity conservation and for the definition of ecological corridors. Sediment retention analysis reveals that, although some river basins in Northern and Central Portugal display high rates of potential erosion, more than 80% of the generated sediments are retained, playing a crucial role in protecting water resources, reducing siltation, and maintaining the functionality of aquatic ecosystems.



Figure 2 – Habitat Quality.

Policy Options and Recommendations

The results of the MonLand project highlight the need to strengthen an integrated approach to soil and ecosystem services management in mainland Portugal, articulating environmental, agricultural, and spatial planning policies. The information produced provides a solid technical basis to support strategic choices and guide differentiated territorial interventions. A first policy option consists of the systematic integration of the Soil Quality Index and ecosystem services into spatial planning instruments, particularly at regional and municipal levels. The use of these indicators can support the identification of priority areas for conservation, restoration, or sustainable productive use, contributing to more informed and territorially tailored decision-making.

Regarding provisioning services, agricultural production highlights the importance of soils in sustaining national productive systems, particularly in areas dominated by cereal crops and extensive farming systems, which are highly dependent on soil quality. The observed spatial variability reflects not only biophysical differences but also agricultural management practices and varying levels of intensification, with direct implications for productivity and the resilience of agri-food systems.

Annual water yield displays a marked spatial gradient, with higher values in the Northern and Central regions, reflecting the influence of climatic conditions, topography, and land use, as well as soil infiltration and storage capacity. These results are particularly relevant for integrated water resources management, climate change adaptation, and the design of soil degradation mitigation policies, especially under scenarios of increasing water scarcity and heightened climate variability.

Overall, the results demonstrate that soil quality and ecosystem services are strongly interconnected, and that their integrated assessment enables the identification of priority areas for intervention, conservation, and sustainable land management, reinforcing the usefulness of the MonLand project within the context of national public policies and in supporting evidence-based spatial planning processes.

A second option involves strengthening and better targeting agri-environmental measures, aligning public support with areas identified as most vulnerable to soil degradation and the loss of regulating services. The use of MonLand results can contribute to a more efficient application of the instruments of the Common Agricultural Policy, promoting agricultural practices that enhance soil conservation, sediment retention, and biodiversity maintenance.

In the environmental domain, the protection and active management of areas with high regulating capacity are recommended, particularly those exhibiting high levels of sediment retention and habitat quality. These

areas play a fundamental role in reducing erosion, protecting water resources, and enhancing ecosystem resilience, and should therefore be considered priorities within conservation and ecological restoration strategies.

Finally, the continued use of the indicators developed within the project is recommended

Conclusion

The MonLand project demonstrates the value of an integrated approach to the assessment of soil and ecosystem services in mainland Portugal, providing robust, spatially explicit, and decision-oriented information. The combination of the Soil Quality Index with the analysis of regulating and provisioning services enables a more comprehensive understanding of the state of the territory and the benefits it provides to society. The results reveal significant territorial contrasts and confirm that soil quality is closely linked to the capacity to deliver essential services, such as erosion protection, biodiversity conservation, agricultural production, and water availability.

as a monitoring tool, enabling the tracking of changes in soil quality and ecosystem services over time. This approach is particularly relevant in the context of climate change adaptation and the fulfilment of national and European commitments related to soil protection, biodiversity conservation, and sustainable land management.

This interdependence reinforces the need for public policies that recognise soil as a strategic resource, integrating environmental, economic, and social objectives. By articulating scientific evidence with validation by institutional stakeholders, MonLand strengthens the credibility and practical applicability of its results. The project thus represents a relevant contribution to the design of more informed, coherent, and territorially adjusted policies, supporting the transition towards more sustainable and resilient land management, in alignment with national and European objectives for soil and ecosystem protection

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