Land-use and land-cover change in a Mediterranean Landscape: a geospatial approach for sustainable and climate-resilient land management

Eduardo Gomes, Portugal, Cláudia M. Viana, Portugal, Jorge Rocha, Portugal

Key words: Land-use and land-cover change, Agricultural intensification, Alqueva region (Portugal)

1. SUMMARY

This study offers a detailed spatial analysis of land-use and land-cover change (LULCC) in the Alqueva region of southern Portugal, a Mediterranean landscape that has undergone substantial transformation in recent years. Much of this change has been driven by the expansion of large-scale irrigation and the intensification of agricultural production systems. Using multi-temporal spatial data from 2007 to 2023, the results reveal a significant increase in intensive agricultural land uses particularly olive groves, almond orchards, and vineyards which have progressively displaced traditional extensive farming systems and semi-natural land cover types. Hotspot analysis identifies statistically significant clusters of agricultural intensification closely associated with the spatial configuration of the Alqueva irrigation network and its surrounding areas. These patterns highlight the central role of water availability in shaping land-use decisions and accelerating the homogenisation of the landscape. The observed trends point to a major reorganisation of the regional agricultural system, with important implications for ecosystem services, water demand, and overall landscape structure. Overall, the findings illustrate the ongoing transformation of the Alqueva region and underscore the need for spatially informed land-use planning and policy frameworks capable of guiding agricultural expansion, mitigating environmental impacts, and supporting sustainable land management in irrigated Mediterranean environments.

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2. INTRODUCTION

Landscapes emerge from long-term interactions between environmental processes and socio-economic dynamics. In Mediterranean regions, traditional agricultural systems have historically given rise to multifunctional landscapes that support both food production and biodiversity conservation (Díez Sanjuán & Migliorini, 2024; Muñoz-Rojas et al., 2019). However, these landscapes are increasingly challenged by agricultural intensification, climate change, and structural shifts in rural economies (Bennett et al., 2021; Zabel et al., 2019). Over recent decades, the Alentejo region in southern Portugal has experienced profound landscape transformations, largely linked with the development of the Alqueva multipurpose dam and its irrigation system. The expansion of irrigated agriculture has facilitated a rapid transition from extensive rainfed systems to intensive, highly mechanized production models, particularly in olive groves, almond orchards, and vineyards (Hermeto de Pádua Souza et al., 2026). While this process has contributed to increased agricultural productivity and regional economic growth, it has also raised concerns related to biodiversity loss, water-use sustainability, and the simplification of traditional landscapes such as the montado, an agro-silvo-pastoral system widely recognized for its ecological and cultural value (Le et al., 2025; Winkler & Pinto-Correia, 2026). Within this context, there is a growing demand for planning-oriented approaches that can anticipate future land-use trajectories and assess their implications for landscape structure and environmental sustainability (C. J. Watson et al., 2024; S. C. L. Watson et al., 2021). Spatial modelling combined with participatory approaches provides valuable tools to support such assessments and to inform more balanced land-use strategies that reconcile agricultural expansion with ecological and socio-economic considerations. Against this background, the present study explores past dynamics of agricultural intensification in the Alqueva region (Portugal). Specifically, it maps land-use changes between 2007 and 2023, identifies spatial patterns of intensification, and interprets these dynamics in relation to broader processes of landscape transformation and land management strategies. By integrating geospatial modelling, the study contributes to ongoing debates on sustainable landscape planning, climate adaptation, and evidence-based land-use policy.

3. DATA AND METHODS

The study area corresponds to the Alqueva region in southern Portugal and covers approximately 8,800 square kilometres across several municipalities in the Alentejo. The region

is characterised by gently undulating terrain, a Mediterranean climate with hot, dry summers, and a long-standing tradition of extensive agricultural land use. The construction of the Alqueva dam, together with the subsequent expansion of irrigation infrastructure, has fundamentally reshaped land-use dynamics by enabling the large-scale establishment of permanent irrigated crops (Morais et al., 2018; Morgado et al., 2022).

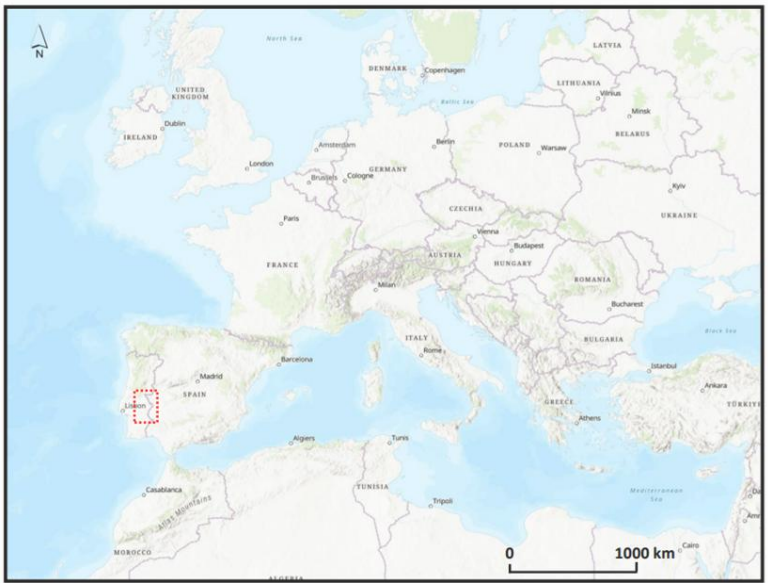

Figure 1 - Spatial extent of the study area within southern Portugal.

Land-use and land-cover data for 2007 and 2023 were derived from the Portuguese Land Use and Cover Map produced by the Directorate-General for Territory. The dataset has a nominal scale of 1:25,000, a minimum mapping unit of one hectare, and a spatial resolution of 25 centimetres. To improve the identification of intensive agricultural systems, high-resolution orthophotos were interpreted visually. Intensive olive groves, vineyards, and orchards were distinguished based on planting geometry, regular spacing, and high crop density. Olive groves typically display planting patterns of approximately six by six metres and are often associated with organised irrigation infrastructures, such as drip irrigation systems. To identify spatial concentrations of agricultural intensification between 2007 and 2023, hotspot analysis was conducted using the Getis–Ord Gi* statistic, allowing the detection of statistically significant clusters of change.

4. RESULTS

4.1 Land use change and expansion of intensive agriculture

The analysis indicates substantial land-use change in the Alqueva region between 2007 and 2023, characterized by a pronounced expansion of intensive agricultural systems. Although the overall agricultural area declined, reflecting the conversion of extensive farming systems, the area occupied by intensive agriculture increased from 377 km² in 2007 to 1,414 km² in 2023, corresponding to a growth of approximately 275%. This expansion occurred mainly at the expense of agroforestry areas, pastures, and forests, all of which experienced notable reductions during the same period. The comparison reveals a clear spatial gradient of intensification associated with the expansion of the irrigation network, with newly established intensive agricultural areas clustering around irrigated perimeters. Olive groves represent the largest share of intensive agriculture, followed by almond orchards and vineyards. Conversion analysis shows that the land-use categories most frequently transitioning to intensive agriculture were temporary dryland and irrigated crops, pastures, and agroforestry systems, including montado. Although conversions from forested areas were less extensive, they nevertheless contribute to landscape simplification and potential habitat loss.

4.2 Spatial patterns and hotspots of intensification

The hotspot analysis specifies additional insight into the spatial structure of agricultural intensification in the study area. Statistically significant hotspots were recognized, particularly in areas directly influenced by the Alqueva irrigation infrastructure. These clusters reflect the combined influence of water availability, accessibility, and favorable biophysical conditions.

Figure 2 illustrates the results of the Getis–Ord Gi* analysis, highlighting areas of statistically significant hotspots and coldspots of intensification. Hotspots are predominantly concentrated near major irrigation canals and road networks, underscoring the role of infrastructure in shaping land-use change. In contrast, coldspots tend to coincide with areas characterized by physical constraints, regulatory restrictions, or the persistence of extensive land-use systems. Overall, these spatial patterns reveal that agricultural intensification is not driven solely by economic factors but is also strongly structured by territorial planning decisions and infrastructural investments. This has critical implications for landscape connectivity, land-use governance, and the preservation of cultural landscape values.

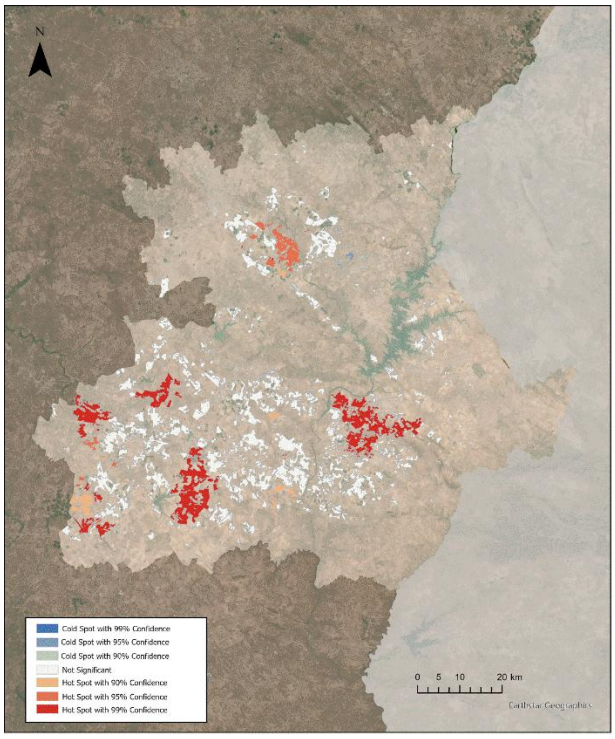

Figure 2 - Hotspot analysis of agricultural intensification (2007–2023) – Alqueva Region.

5. DISCUSSION: IMPLICATIONS OF LAND-USE AND LAND-COVER CHANGE

The observed expansion of intensive agriculture in the Alqueva region has significant implications for landscape structure and long-term sustainability. The replacement of heterogeneous landscape mosaics with large-scale monocultures contributes to land-cover simplification, leading to reduced spatial diversity and the disruption of traditional land-use patterns (Cortés-Capano et al., 2025; Jian et al., 2025). In particular, the decline of the montado system correspond to a profound transformation of a multifunctional landscape historically associated with ecological stability and diversified management practices (Helena Guimarães et al., 2023; Ishaq et al., 2025). Spatial analysis reveals areas of concentrated intensification, closely associated with the irrigation network. These patterns help recognize areas where land-use change is most pronounced and where targeted management interventions may be required to maintain landscape heterogeneity and ecosystem resilience. At the same time, the persistence of mixed land-use and agroforestry systems in certain parts of the region shows that the impacts of intensification are not spatially uniform. Maintaining a balance between intensive agricultural production and multifunctional landscapes is therefore essential to preserve ecological functions, support biodiversity, and strengthen the adaptive capacity of rural systems (Killion et al., 2018; Rusch, 2025).

From a planning perspective, the spatially explicit identification of hotspots, and transition areas requires valuable evidence to guide sustainable land-use decisions. These findings resonate with broader policy debates on post-2030 development and climate resilience. As water scarcity intensifies and climate pressures increase, the sustainability of highly water-dependent intensive systems may be challenged (Al-Maadid et al., 2025; Ravinandrasana & Franzke, 2025). Planning strategies that account for landscape diversity, multifunctionality, and resilience can contribute to more adaptive and socially inclusive land-use futures (Shiri et al., 2025; Zoumides et al., 2025).

6. CONCLUSIONS

This study demonstrates how agricultural intensification has reshaped, and is likely to continue reshaping, the landscapes of the Alqueva region in southern Portugal. Between 2007 and 2023, intensive agriculture expanded rapidly, particularly within irrigated areas, driving a transition from heterogeneous, multifunctional landscapes towards large-scale monocultural systems. Spatial modelling and hotspot analysis reveal clustered patterns of change that are closely associated with infrastructure development, accessibility, and the irrigation network. The findings highlight the growing challenge of reconciling agricultural productivity with the conservation of landscape heterogeneity and multifunctional systems such as the montado. By providing spatially explicit, evidence-based insights, this study supports planners and decision-makers in anticipating future land-use trajectories and in designing strategies that promote both agricultural development and landscape sustainability. The methodological approach presented here is transferable to other regions facing similar pressures and contributes to broader discussions on sustainable land-use planning, climate adaptation, and the resilience of rural landscapes. Overall, the results underscore the importance of spatially informed planning in guiding adaptive, balanced, and resilient land-use transitions.

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BIOGRAPHICAL NOTES

CONTACTS

Eduardo Gomes
Centre of Geographical Studies (CEG), Associate Laboratory TERRA, Institute of Geography and Spatial Planning (IGOT), Universidade de Lisboa, 1600-276 Lisbon, Portugal
R. Branca Edmée Marques, 1600-276
Lisboa
PORTUGAL
Email: eduardojonas@edu.ulisboa.pt
Web site: https://ceg.igot.ulisboa.pt/pessoas/eduardo-jonas-gomes

Cláudia M. Viana
Centre of Geographical Studies (CEG), Associate Laboratory TERRA, Institute of Geography and Spatial Planning (IGOT), Universidade de Lisboa, 1600-276 Lisbon, Portugal
R. Branca Edmée Marques, 1600-276
Lisboa
PORTUGAL
Email: claudiaviana@edu.ulisboa.pt
Web site: https://ceg.igot.ulisboa.pt/pessoas/claudia-viana

Jorge Rocha
Centre of Geographical Studies (CEG), Associate Laboratory TERRA, Institute of Geography and Spatial Planning (IGOT), Universidade de Lisboa, 1600-276 Lisbon, Portugal
R. Branca Edmée Marques, 1600-276
Lisboa
PORTUGAL
Email: jorge.rocha@edu.ulisboa.pt
Web site: https://ceg.igot.ulisboa.pt/pessoas/jorge-rocha