Received: 9 May 2024 | Revised: 8 October 2024 | Accepted: 7 November 2024

DOI: 10.1002/geo2.161

Open Access Geo Royal Geographical Society with IBG WILEY

ARTICLE

Analysis of the dynamics of the land use changes in the Mediterranean region of southern Spain and its relationship with water availability

J. A. Sillero-Medina[1] | F. B. Galacho-Jimenez[2] | J. Molina[3] | J. D. Ruiz-Sinoga[1]

[1]Habitat, Territory and Digitalization Institute, University of Malaga, Malaga, Spain

[2]Geographic Analysis Group, Department of Geography, University of Malaga, Malaga, Spain

[3]Department of Applied Economics, Mathematics, Faculty of Economics, University of Malaga, Malaga, Spain

Correspondence
J. A. Sillero-Medina, Habitat, Territory and Digitalization Institute, University of Malaga, 29071 Malaga, Spain.
Email: jasillero@uma.es

Funding information
Ministerio de Economía y Competitividad, Grant/Award Number: PID2019-104046RB-100; Ministerio de Ciencia e Innovación, Grant/Award Number: TED-2021-129664B-C22; CRUE/CBUA CY24 - Universidad de Málaga

Abstract
In the recent decades, the increase in irrigated agricultural areas has been a constant trend in the Mediterranean region, being concurrent with a reduction in the availability of water resources, due not only to an increase in demand but also to a reduction in supply as a result of the climate crisis. This study has analysed the evolution in land use changes between 1991 and 2021 in the Mediterranean region of southern Spain; the increase in the areas occupied by irrigated crops has been quantified; the climatic and edaphic dynamics linked to water risks have been identified, analysing the evolution of the annual precipitation, the number of rainy days and the distance to the wilting point of the soil; and, finally, it has been determined which factors are the most explanatory in this dynamic of land use. Using several machine learning methods, we could state how the current dynamics of land use are not in accordance with the availability and evolution of water resources, and how the areas where irrigated crops have increased the most are those where the climatic pattern shows a greater decrease in water resources, indicating how decisions on land uses are not done considering climatological conditions, but economic benefits.

KEYWORDS
available water, climate change, irrigated crops, land use changes, machine learning, Mediterranean

1 | INTRODUCTION

The rural areas of southern Spain, and specifically those in the Mediterranean area, have historically been suffering an uneven process of development and occupation, a process largely related to the development of their agricultural and productive approaches and their location or proximity to urban spaces (Criado et al., 2020; Meeus et al., 1990;

The information, practices and views in this article are those of the author(s) and do not necessarily reflect the opinion of the Royal Geographical Society (with IBG).

Ruiz & Sanz-Sánchez, 2020; Serra et al., 2008). This has produced different agricultural approaches and a different diversification of agricultural production over time (Casas et al., 2015; Saadi et al., 2015). In this context, Mediterranean agriculture has followed a clear trend towards the increase of new irrigated land in old rainfed lands (Martí & García-Mayor, 2020; Serrano et al., 2022). This dynamic is evolving without considering the available resources: water and soil, adhering almost exclusively to the dictates of markets and demand without any consideration of its ecological footprint (Caparrós-Martínez et al., 2020; Duarte et al., 2021; García-Marín et al., 2020; Rossi, 2015). However, the Mediterranean region is widely recognized as one of the most exposed in the world to the effects of climate change, water scarcity, biodiversity loss and land degradation, proportional to the nutritional transition and the size of its populations (Antonelli et al., 2022; Capone et al., 2021). This situation is not desirable and is having negative consequences, which are becoming more evident every day (Fader et al., 2016; Giannakopoulos et al., 2009). Therefore, it is essential to understand how the dynamics of land use changes are occurring and their relationship with eco-geomorphological processes (Calvo-Cases et al., 2021; Slaymaker et al., 2009).

Studies on land use changes are the focus of much recent research on rural areas (Grabska-Szwagrzyk et al., 2024). One of the most frequent perspectives is addressing its dynamics through the analysis of the causes and consequences of its transformation, degradation by human activities and the effects of climate change (Hasan et al., 2020; Jiménez-Olivencia et al., 2021). The effects of changes in uses in the natural environment are analysed in their effects on ecosystem services and their repercussions on the functioning of natural ecosystems, as the role of transformations of vegetation cover and forests in climate regulation (Beilin et al., 2012; Cui et al., 2021; Millán, 2014; Sun et al., 2021). This line also deals with the impacts and consequences of changes from the perspective of the functioning of physical cycles, how changes in land use alter surface runoff, affecting hydrological processes and this fact being accentuated by the modification of precipitation and temperature patterns due to climate change (Daneshi et al., 2021). In the Mediterranean regions, certain processes of land degradation due to abandonment of agriculture, and vice versa, trigger changes in land use (Corbelle et al., 2012; Melendez et al., 2014; Tomaz et al., 2013). Other studies relate competition for land uses and the deterioration of physical or natural conditions: the deterioration of soil quality in areas with higher agricultural capacity and the depletion of water resources as factors that activate or favour the dynamics of changes towards other uses and towards the irruption of urban uses in the long term (Ferrara et al., 2014; Haregeweyna et al., 2012; Luo et al., 2020; Obiahua & Elias, 2020; Song & Liu, 2014).

The hydrological status of the soil is fundamental to determine which crops are suitable in a given area and how to manage them efficiently, by measuring the water availability for plants (Campos et al., 2016; Kirkham, 2005). By understanding the amount and distribution of water in the soil, it can be determined whether there is enough water to sustain crop growth and development. This is especially crucial in areas where precipitation is limited or irregular (Negri et al., 2005). In addition, through knowledge of the hydrological state of the soil, the irrigation needs of crops can be determined, as well as the selection of suitable crops. Some plants have greater drought tolerance, while others prefer well-drained soils (Martínez-Fernández et al., 2001; Ruiz-Sinoga et al., 2011). So, by knowing the characteristics of the soil, such as its water retention capacity and drainage, one can choose which crops will be most successful in that particular area (Ruiz-Sinoga et al., 2010a; Ruiz-Sinoga & Romero-Diaz, 2010; Ruiz-Sinoga et al., 2010b). However, soil hydrology also affects the availability and mobility of nutrients for plants. A too dry or too wet soil can make it difficult for crop roots to absorb nutrients. Therefore, understanding the hydrological status of the soil helps to adjust fertilization and nutrient management practices more precisely, and allows to prevent problems such as soil erosion and deterioration. If the soil is dry and prone to erosion, water conservation measures and proper management practices can be implemented to protect the soil. Similarly, if the soil is saturated by water, actions can be taken to improve drainage and avoid waterlogging problems.

So, soil needs to have a useful water content to supply to the root system of the plant which must be above the permanent wilting point threshold (Kirkham, 2005; Martínez-Fernández, 1996), for several reasons:

- Because it ensures that plants have enough water available for their needs. Water is essential for the growth, development and proper functioning of plants. If soil is below the wilting point, plants can suffer water stress, which will affect their health and yield.
- Because water in the soil is the way through which plants obtain dissolved nutrients (Laio et al., 2001; Ruiz-Sinoga et al., 2011; Ruiz-Sinoga et al., 2010a). When soil has an adequate water content, nutrients in the soil dissolve and are available to be absorbed by the roots of the plants. If the soil is too dry, nutrients can become inaccessible to the roots, which can lead to nutritional deficiencies and affect plant growth.

- Because it affects its structure and texture (Fernández & Trillo, 2005; Gabarrón-Galeote et al., 2013; Martínez-Fernández, 1996; Ruiz-Sinoga & Romero-Diaz, 2010; Ruiz-Sinoga et al., 2010b). Water acts as a binding agent for soil particles, helping to maintain their cohesion and form stable aggregates. When the soil is dry, it can become compact and hard, making it difficult for roots to grow and water and nutrients to penetrate. Maintaining an adequate water content helps maintain a healthy soil structure and promotes root development and airflow in the soil.
- Because an adequate water content in the soil is also important to maintain its biological activity (Laio et al., 2001; Ruiz-Sinoga et al., 2011). Beneficial soil microorganisms, such as bacteria and fungi, require water for their survival and activity. These organisms play a crucial role in the decomposition of organic matter, the cyclization of nutrients and the improvement of soil structure. Without enough water, biological activity can decrease, which can negatively affect the overall health of the soil and its ability to maintain a favourable environment for plant growth.

In summary, maintaining a water content above the permanent wilting point is important to ensure water availability for plants, facilitate nutrient uptake, maintain healthy soil structure and support biological activity. This promotes optimal plant growth and development and contributes to successful agricultural production.

In this sense, the objectives proposed for this study are the following: (i) determining the dynamics of land use changes in the Andalusian Mediterranean basin between 1991 and 2021, emphasizing the area occupied by irrigated crops; (ii) analysing trends in different climatic and soil variables associated with water risks; (iii) identifying those significant variables that are determining the current dynamics in land use changes.

2 | MATERIALS AND METHODS

The main goal of this work is to demonstrate how the dynamics of changes in land use are evolving without considering the available resources, specifically the availability of water (Vila-Traver et al., 2021) and the soil conditions in a context of extreme climatic situations happening in a changing climate environment. To this aim, we propose a methodological approach that can be seen in Figure 1, and that will be described in detail in all its points along this section.

2.1 | Study area

The study area was southern Spain, specifically, the Andalusian Mediterranean basin, determined by a rainfall gradient ranging from 1400 mm of annual rainfall in the extreme west (humid Mediterranean climate) to 150 mm of annual rainfall in the east (arid Mediterranean climate) (Figure 2). This territory is dominated by a Mediterranean landscape of

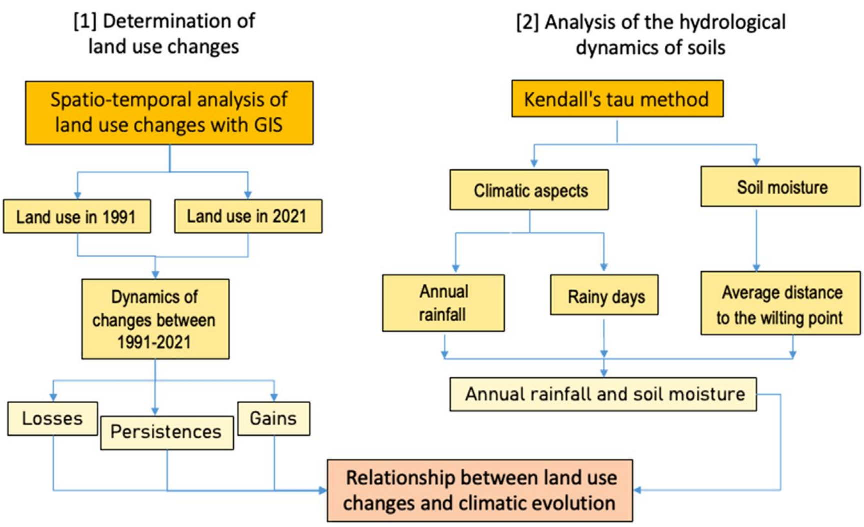

FIGURE 1 Methodological approach to relate to demonstrate the relationship between changes in land use and the evolution of climatic factors.

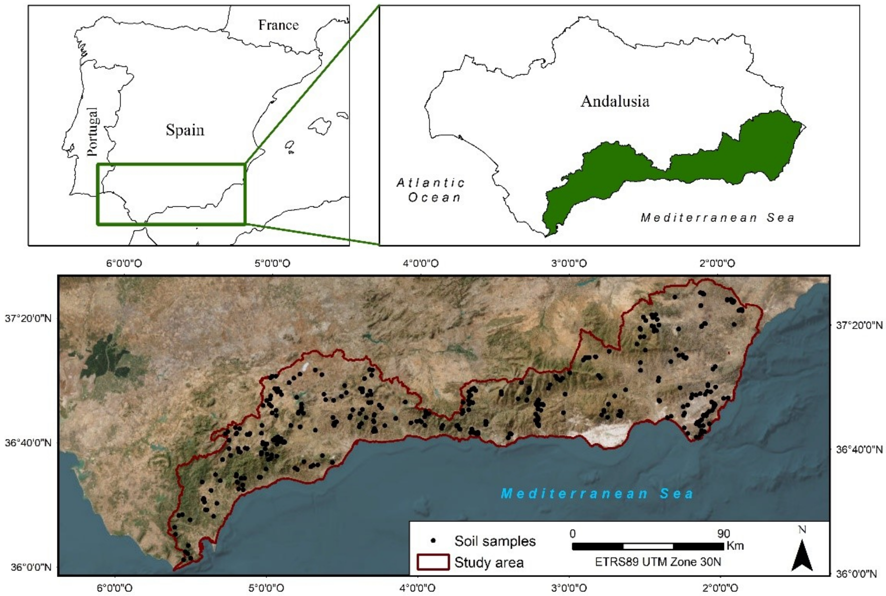

FIGURE 2 Location map. Selected study area and soil sample points.

mid-mountain, consisting mainly of the Palaeozoic Baetic land relief, of slates, schists and marbles, and with a vegetation cover so modified by human activity for more than 2000 years.

The Andalusian Mediterranean has become a space of great sensitivity during the last half century, especially due to extraordinary urban development, and the modification of different agricultural and forestry uses. Thus, during the second half of the last century and until today, there have been a whole series of changes in land use, with unequal response from the eco-geomorphological system.

Among the main traditional agricultural uses of this region are the almond tree, the vine and the olive tree, all of which are cultivated in dry land. However, in recent decades, irrigated crops have become more important, expanding considerably. In these irrigated areas there are large extensions of fruit trees (citrus and subtropical) and other crops, mainly vegetables, which are grown under greenhouses.

2.2 | Data source

The rainfall analysis was implemented using data obtained from the Red S.A.I.H. Hidrosur, for a total of 98 meteorological stations distributed throughout the study area (Figure 2). The data series covers the period from 1997 to 2022, using a temporal resolution of 10 min.

Relating the data for the spatio-temporal analysis of land use changes, we used the layers of land use and vegetation cover of Andalucía for two dates: years 1991 and 2021. For the first date, 1991, we used the cartography of the uses and vegetation covers of the soil of Andalusia of the year 1984, at a scale of 1:25,000, updated between 1988 and 1990. For the second date, 2021, we used the information layer of the System of Geographic Information of Agricultural Parcels, SIGPAC of that same year. It is a graphical database with an accuracy equivalent to at least 1:10,000 scale cartography. This information is built from the rustic digital cadaster of the General Directorate of the Cadaster of the Ministry of Finance of the Government of Spain, taking as auxiliary information diverse sources of the Institute of Cartography and Statistics of Andalusia and other Ministries, among which we highlight the orthophotography at scale 1:5000 of the flight 1:20,000 of the years 2001 and 2002.

The land use layers used (1991 and 2021) constitute the compilation of all the necessary information to support the analysis with remote sensing, as well as the compilation and organization of the basic reference images (satellite images) for their integration, along with the rest of the geographic information in a GIS. All prior treatments related to image correction and the generation of normalized vegetation indices (NDVI), as well as verification and photogrammetry work, had already been validated by the SinambA technicians (Environmental Information System of Andalusia) according to criteria directly emanated from the European Reference Center for Environmental Information, the European

Environment Agency (EEA) itself, which were adopted by these environmental technicians of the Autonomous Community of Andalusia (Moreira-Madueño, 2006).

Finally, from different geographical characteristics of the territory such as the slope, the lithological unit or the different uses of the soil, a total of 400 samples of surface soil (0–10 cm deep) distributed throughout the territory have been collected. In the laboratory, these soil samples were air-dried and sifted, and fractions with particle sizes <2 mm were removed for further analysis of the main soil properties. Concretely, bulk density (BD), soil texture, organic matter (OM), organic carbon (OC), structural stability (AS), permeability, as well as water retention capacity (field capacity, wilting point and available water content) were analysed. The methods used for these measurements were described by Ruiz-Sinoga and Romero-Diaz (2010).

2.3 | Determination of land use change processes

There are several methods for the spatio-temporal analysis of land use (land cover change -LCC-) with Geographic Information Systems (GIS) (Humacata, 2019; Nagendra et al., 2004; Tadese et al., 2020).

The conceptual design of the change analysis begins with the selection of the time derivative, which, as previously mentioned, focuses on the years considered: 1991 and 2021. The year 1991 is taken as a reference for the decade of the 1980s and early 1990s of the twentieth century, which meant a few moments of expansion of agricultural production in the context of an accelerated economic dynamic that had a few moments of slowdown with the crisis of 1992. Finally, the reference to the present is determined by the year 2021. The land uses´ map of this year reflects the result of many particular spatial processes: the consolidation of the expansion of urbanism in coastal agricultural spaces and in the peri-urban areas of the metropolitan areas of the provincial capitals that was leading to the disappearance of agricultural areas, the concentration in certain areas of the expansion of intensive irrigated agriculture to supply a growing demand and the consolidation of market approaches towards an industrialized agriculture.

Another key aspect in the determination of the methodological frame is the definition of the land use classes that will be crucial in the changes analysis, as it will determine the meaning of the changes occurring and their relation to the evolution of climatic conditions. In this sense, we have selected seven land use classes, synthesizing the peculiarities and diversity of agricultural production systems related to the dynamics of irrigation uses:

1. Permanent irrigated crops (PIC): crops with a constant permanence in the territory and, so, less vulnerable to change. They are usually irrigated woody or fruit crops and are maintained under various irrigation systems.
2. Irrigated agricultural land (IAL): Irrigated land whose permanence is less stable than PICs, being so more vulnerable to climatic fluctuations and characterized by being seasonal crops. It includes herbaceous uses on irrigated land, but also other uses so dependent on the water balance.
3. Permanent rainfed crops (PRC): Uses highly adapted to the prevailing climatic conditions in Mediterranean environments. It includes crops maintained over time and their productivity depends on how both the water balance and temperatures evolve.
4. Rainfed Agricultural Areas (RAA) and Heterogeneous Rainfed Agricultural Zones (HRAZ): Spaces where the types of uses are selected depending on the climatic conditions, therefore, no-permanent crops are usually found, as well as uses of a single kind of crop or a mixture of different uses. In these areas, we can also find uncultivated spaces and bare soils that remain waiting to be cultivated.
5. Greenhouses (G): Cultivation systems under plastic. These are permanent uses and depend more on their economic profitability than on climatic conditions. Currently, they occupy large areas of cultivation and are on an increasing trend.
6. Open spaces with shrub and forest vegetation (OSSFV) and Shrub and herbaceous vegetation spaces (SHVS): Areas with natural and non-agricultural vocation. These areas are frequently used as cultivation land, although their edaphic characteristics are not the most suitable. So, are prone to abandonment and very vulnerable to erosion.
7. Spaces with dense shrub and forest formations (SDSFF). This is a class of very little agricultural vocation, which, however, has been used in many areas for cultivation. Of low agricultural productivity, are so prone to abandonment.

The classes of uses that have been the object of the analysis in this study are the result of a classification system implemented by the authors and are not directly determined by the classes contained in the cartographic bases used for the analysis. It has been applied a process of normalization of the data model contained in each of the layers that, among other aspects, has consisted in a homogenization of the nomenclature of the classes and analysis for the assignment of correspondences. Once the classes of uses have been defined, the dynamics of changes are analysed. A period of 30 years has been selected to measure changes: 1991–2021. The methodology used was proposed by Pontius et al. (2004) for the analysis of patterns of change in land use, and for the analysis of its special distribution, we used the geoprocessing tools provided by GIS software. This methodology has been used by numerous authors for the quantitative analysis of changes in land use (Damián et al., 2018; Farfán et al., 2016; Hamacara et al., 2019; Pérez & Bosque, 2008). To this aim, two data layers were used, with the land uses corresponding to the dates mentioned. Using the geoprocessing tools, the geometric intersection of the two layers was performed, creating a new layer that computes the matches of both and their associated attributes.

The results of the operation performed are transferred to a transition matrix or crosstab matrix P, shown in Table 1. This matrix lists the classes of the time cut 1 (1991) in the rows and the classes of the temporal cut 2 (2021) in the columns. The data distribution in the matrix is shown in Table 1: on the diagonal, by classes of use, the surfaces that remained stable between both temporal cuts, this is, the surface of each class of use j that remains in class j (Pjj). Outside the diagonal, we can find the transitions between both time cuts, quantified in surfaces (ha), of those same classes of use Pij: the surface of class of use i in 1991 that has undergone a transition to the class of use j in 2021.

According to this definition, we can define the losses (from 1991 to 2021) on a given class j as the difference between the sum of row j of the matrix P (Pj*) and the diagonal value on that row, where the persistence is located (Pjj), representing the surface of each class j that experiences net losses in the period studied, expressed as: $Lj = Pj^* - Pjj$. On the contrary, gains are the difference between the sum of column j of the matrix (P*j) and the diagonal value on that row, where the persistence is located (Pjj), expressed as: $Gj = P^*j - Pjj$. Once losses and gains are defined, we compute the Total Change for each use class j as the total surface changing its use form or to class j, expressed as: $TCj = Lj + Gj$. Finally, the Net Change of use class j is defined as the total surface in class j in 2021 minus the total surface of class j in 1991, expressed as: $NCj = P^*j - Pj^*$. These results can be found in Table 2 and will be commented and analysed in Section 3.1 (Galacho-Jiménez & Reyes-Corredera, 2024).

TABLE 1 Matrix of the types of changes in use between 1991 and 2021.

USES	[1]-2021	[2] -2021	[3] -2021	[4] -2021	[5] -2021	[6] -2021	[7] -2021
[1] -1991	12,143.09	239.99	1737.56	3003.35	231.00	3993.44	894.50
[2] -1991	19,884.01	3153.41	10,301.72	30,404.92	2334.72	14,432.29	2409.26
[3] -1991	26,549.82	362.82	108,877.75	21,443.75	1135.74	37,009.01	8018.51
[4] -1991	32,014.52	960.04	80,533.88	68,354.35	2534.86	66,165.74	14,758.78
[5] -1991	308.43	269.73	90.07	1008.65	3882.25	1135.86	24.37
[6] -1991	20,872.94	1086.09	27,633.25	46,346.37	3897.04	460,183.13	136,041.00
[7] -1991	5039.99	111.42	7305.53	5000.13	155.47	70,867.06	184,833.03

Note: Areas in ha. On the diagonal are marked the areas of unchanged use classes.

[1] PIC: Permanent Irrigated Crops, [2] IAL: Irrigated Farmland, [3] PRC: Permanent Rainfed Crops, [4] RAA: Rainfed Farmland and HRAZ: Heterogeneous Rainfed Agricultural Zones, [5] G: Greenhouses, [6] OSSFV: Open Spaces with Shrub and Woodland Vegetation and SHVS: Shrub and Herbaceous Vegetation Spaces, [7] SDSFF: Spaces with Dense Shrub and Woodland Formations.

TABLE 2 Matrix of the dynamic of changes in land use between 1991 and 2021 for the study area (ha).

	1991	2021	Losses	Gains	Total change	Net change
	T1 (Pj*)	T2 (P*j)	$Lj = Pj^* - Pjj$	$Gj = P^*j - Pjj$	$TCj = Lj + Gj$	$NCj = P^*j - Pj^*$
[1]	22′242.93	116′812.80	10′099.84	104′669.71	114′769.55	94′569.87
[2]	82′920.33	6′183.50	79′766.92	3′030.09	82′797.01	−76′736.83
[3]	203′397.40	236′479.76	94′519.65	127′602.01	222′121.66	33′082.36
[4]	265′322.17	175′561.52	196′967.82	107′207.17	304′174.99	−89′760.65
[5]	6′719.36	14′171.08	2′837.11	10′288.83	13′125.94	7′451.72
[6]	696′059.82	653′786.53	235′876.69	193′603.40	429′480.09	−42′273.29
[7]	273′312.63	346′979.45	88′479.60	162′146.42	250′626.02	73′666.82

2.4 | Analysis of the hydrological dynamics of soils

In order to establish the time trend of annual rainfall and soil moisture, we use the Kendall's tau method, which has been shown so appropriate for this aim in many publications, as Lana et al. (2008), where they state that 'trends of deduced by the Kendall's tau procedure should be more accurate than those obtained by linear regression'. This same procedure has been shown to be so appropriate (and superior) to measure time trends on precipitation in Zhang et al. (2004) or Kunkel et al. (1999). This nonparametric test is based on the count of pairs of data values in the time series for which the difference is either positive or negative (looking forward in time), rather than the magnitude of the difference, which helps minimize the effect of extreme values.

The variables considered to measure the changes in the annual rainfall and the soil moisture patterns are the total annual precipitation, the annual number of days with precipitation and the average distance to the wilting point. This last variable, distance to the wilting point, measures the number of litres above the wilting point in a given location, as an indicator of the moisture state in the soil and its evolution. The closer this value is to 0, the closer the soil is to achieving the wilting point, so the more water stress the soil is suffering. The values of this variable in the time horizon were obtained from Sillero-Medina et al. (2021), where many variables related to soil moisture in the area are provided and analysed.

These three variables cover the information required to estimate a change or reduction in the moisture in the soil so that it could be a cause of a change in the land use. And to these three variables, for each meteorological station, we compute the Kendall's tau, to measure possible time trends. The closer the value of tau to −1, the more decreasing the time trend and, reversely, the closer the value to 1 the more increasing the time trend. The results have been mapped using spatial interpolation techniques. For all cases, we used 70% of the data for calibration and 30% for validation. Regarding the accuracy and selection of the method, in all cases, the variogram and the prediction errors, for both simple and ordinary kriging, were analysed. In both cases, an exploratory data analysis was also performed beforehand (histogram analysis, normal distribution analysis, and trend analysis). We analysed variable by variable (rainfall, rainy days, and distance to wilting point) to observe the fit of the different types of kriging, and, in all cases, simple kriging has been better, and so have been used in all the cases.

2.5 | Relationship between land use changes and climatic evolution

Once the main features of the climatic evolution and the land use changes are identified, it is important to determine which variables have been more significant in these land use changes, this is, if the land use changes are motivated by climatic changes or are rather due to other socio-economical factors. To this aim, Random Forest method is applied, a machine learning algorithm developed by Breiman (2001), that combines the output of multiple decision trees to reach a single result. Random Forest is an ensemble method, made up of a set of classifiers—decision trees—and their predictions are aggregated to identify the most probable result. Random Forest also implements a bagging procedure: several random samples of data in the training set are selected (with replacement). For each sample, a decision tree is trained independently, and the average of those predictions yields a more accurate estimate. Random Forest also uses feature randomness (a.k.a. feature bagging) that generates a random subset of features to ensure low correlation among decision trees, to create an uncorrelated forest of decision trees. Among the benefits of this method, we must outline a reduced risk of overfitting, being able to provide feature importance and a reported better performance than other methods for many problems in the field, as detailed in Section 4.

Relating the details of the Random Forest application, a 10-fold cross-validation approach was used to select the best parameter setting to obtain the best performance, this is, the setting with the maximum average score on the validation set. With this procedure, we tried to find the best possible combination of values of the following parameters:

- Number of trees: The number of trees in the forest, whose possible values were {500, 600, 700, 800, 900, 1000}.
- Minimum sample: The minimum number of samples required to be at a leaf node. A split point at any depth will only be considered if it leaves at least this number of training samples in each of the left and right branches. This may have the effect of smoothing the model, especially in regression. The possible values considered were: {5, 10, 15, 20, 25, 30}.
- Maximum features: The number of features to consider when looking for the best split (as a fraction of the total number of features), whose possible values were {0.1, 0.2, 0.3, 0.4, 0.5, 0.6}.

After trying all the possible combination of parameters, using a maximal depth in all the cases of 10,000, the parameter setting obtaining the maximum average score over the 10 fold cross validation executions was:

- Number of trees: 700
- Minimum sample: 5
- Maximum features: 0.4

This setting obtained an average score of 0.91220, and these parameters were used for the final results of the Random Forest approach.

3 | RESULTS

3.1 | Land use dynamics between 1991 and 2021

During the last 30 years, the dynamics of land use in the Mediterranean Basin of southern Spain has been characterized by the agricultural transformation towards irrigated cultivation or, in other case, towards the abandonment or transformation of old agricultural land to urban or related uses. Tables 1 and 2 show how the number of surfaces changing their use has been significant in many cases. The dynamics of changes show two trends: the consolidation of irrigated land as a permanent crop based on irrigated arable land and, on the contrary, new irrigated crops on old rainfed arable land, something suggesting that they were crops of little consolidation or of a temporary nature. At the same time, and as a second trend, we can find lands that never had an agricultural vocation and now have been converted to irrigated cultivation, mainly happening in spaces of shrub and herbaceous vegetation (mainly pastures). And, what may be more worrying is deforestation for the cultivation of spaces with dense shrub and woodland formations, inducing considerable environmental deterioration.

Based on the methodology proposed by Pontius et al. (2004) for the analysis of the patterns of change in land use and its spatial distribution (that was described in the methodology section), we show in Table 2 the dynamics of the changes based on the quantification of the surfaces of each class that hanged its use and those that have remained the same between the two periods analysed: 1991–2021.

From the territorial perspective, in the study area, we can find changes in agricultural uses, which in many cases have been examples of spectacular modification of the territory, as the case of the consolidation of intensive crops of high market value in the coastal area: the Axarquía in the province of Malaga, the Costa Tropical in Granada and the Levante Almeriense in Almeria, where it is clearly shown the agricultural potentials are not absolute determining factors for cultivation. In Figure 3, we show this territorial distribution that has been quantified in Tables 2 and 3. There are four areas where the changes have been more sounding, and that are highlighted in Figure 2.

3.2 | Precipitation and soil moisture evolution in the period 1997–2022

The climatic dynamics associated with water risks are summarized in Figure 4, where, from a spatial perspective, a maximum concern is found in practically the entire surface of the Andalusian Mediterranean basin. The cartography represents the values of the Mann-Kendall Tau for the series of years between 1997 and 2022 and the variables of: (i) annual rainfall; (ii) number of rainy days; and (iii) distance to the point of ground wilting. As mentioned in Section 2.4, the closer is this value to −1, the more decreasing the time trend and, reversely, the closer the value to 1 the more increasing the time trend.

Firstly, in terms of annual rainfall, there is a quasi-generalized decreasing evolution, highlighting the area of the Axarquía and the Costa Tropical of Granada, where we can find the higher annual rainfall loss with a Tau value of −0.22. In contrast, the easternmost area, with arid climatic conditions, shows a lower rate of change and even a slight increase in its annual rainfall (Tau = 0.05). In contrast, the dynamic on the number of rainy days is so similar to the observed with the annual rainfall, but showing a lower decrease, especially in the eastern are. In this sense, the values of the Mann-Kendall Tau range from −0.22 (maximum) to −0.07 (minimum). At the same time, we can conclude an increase in the rainfall intensity in most of the Mediterranean basin, as the number of rainy days undergoes a higher reduction than the annual rainfall.

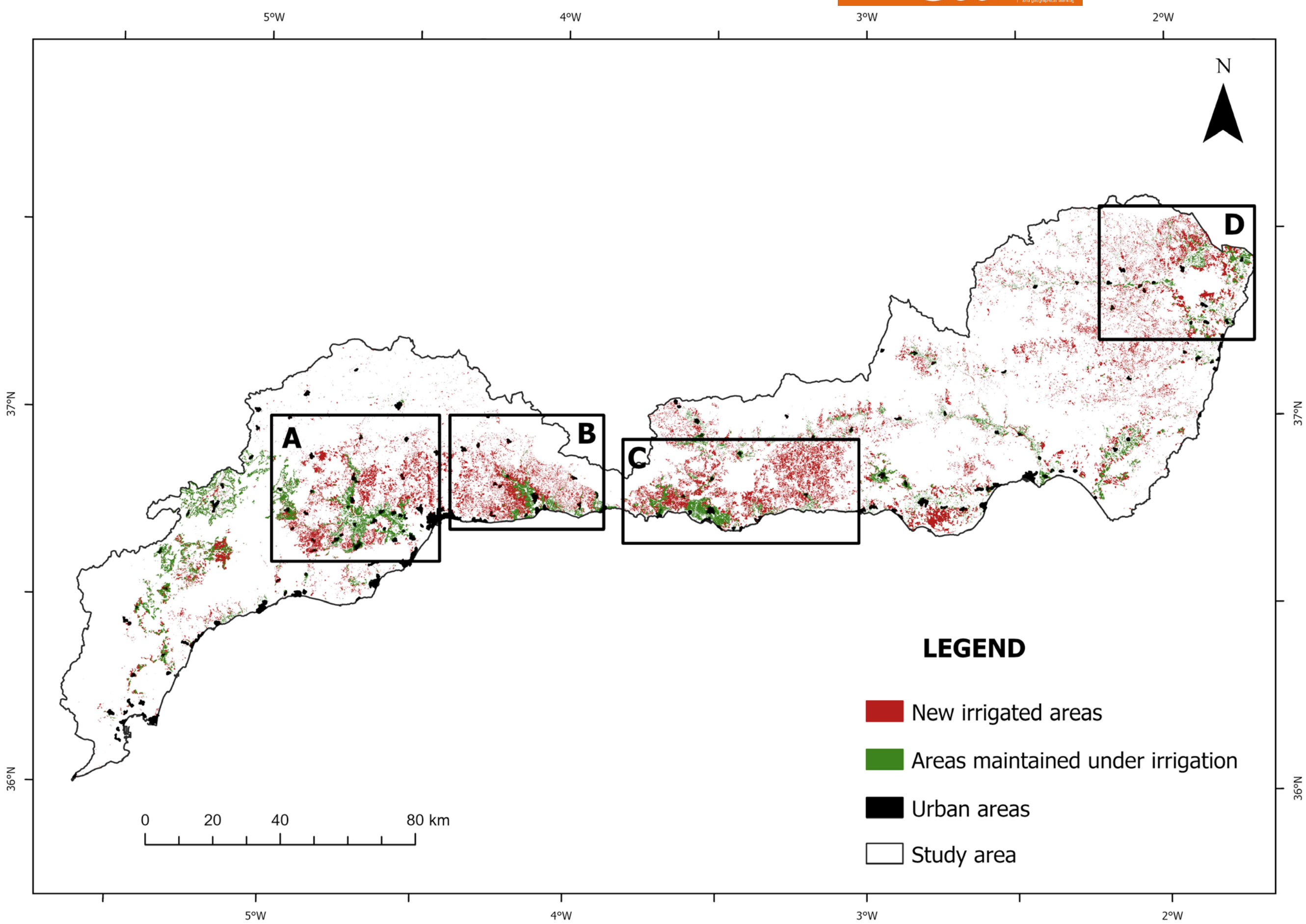

FIGURE 3 Location of the main zones of change of use in the study area. Zone A: Guadalhorce Valley and metropolitan area of Malaga; Zone B: Axarquia in the province of Malaga; Zone C: Costa Tropical of Granada; Zone D: Levante Almeriense in the province of Almería.

TABLE 3 Quantification of the change surfaces is shown in Figure 2.

Dynamics of irrigated crops	Increment area (ha)	Area of increment (%)	Percentage of irrigated areas in the study area
New irrigated areas	151.029,83	66,31	8,29
Areas maintained under irrigation	76.743,62	33,69	4,21
Total area of irrigated areas	227.773,45	100,00	12,51

Considering the distance to the wilting point in the soil, results show a higher spatial heterogeneity. However, the negative trend is more spread in the area studied, showing how soils are increasingly closer to water stress. Thus, the greatest intensity of decrease is observed in the Costa Tropical of Granada (Tau = −0.12), followed by the Axarquía and the westernmost sector of the province of Malaga, both with a Tau of −0.09.

In short, considering the three variables analysed, a clear pattern is determined in the territory, with some hot spots linked to this availability of water, such as the Costa Tropical and the region of Axarquía (Malaga). On the contrary, in the extreme east, of arid climatic conditions, is where a lower variation of these variables has been observed, obtaining Tau values closer to 0. But the general pattern is of a reduction in water availability and a trend to get closer to water stress, something being in contradiction with the increase in the irrigated surface shown in Section 3.1, as the increase on irrigated surface should be accompanied with an increase on the precipitation to supply that extra consume on water resources.

Finally, in Table 4 we are including the main descriptive statistics, and in Table 5, the correlation coefficients of the data used for the maps are included, so that the reader can have a more precise idea on the distribution and main characteristics of the data.

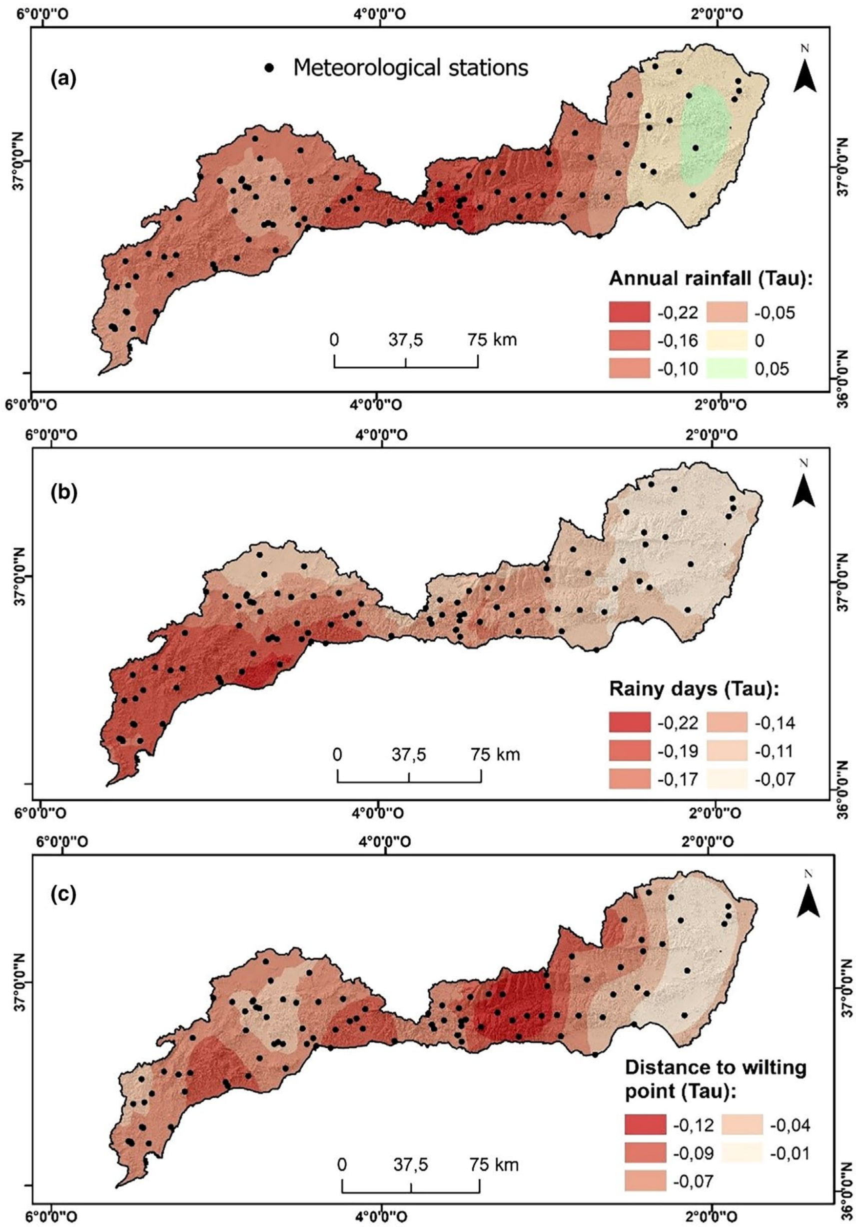

FIGURE 4 Rainfall and soil moisture dynamics (a) Annual rainfall; (b) Rainy days; (c) Distance to wilting point.

3.3 | Relationship between land use changes and climatic evolution

As mentioned in a previous section, a Random Forest method is used to relate the main climatic characteristics with the variation of the percentage of irrigated surface, to try to establish how the dynamic on the land use changes is related to the climatic evolution. As shown in Sections 3.1 and 3.2, two contradictory patterns can be observed: the surface of irrigated crops is increasing, this is, the demand for water resources is increasing, while the availability of water is decreasing. This is, in general, the annual rainfall is decreasing, but a higher demand is observed while a lower offer is also observed. So, to confirm this contradictory (and counterproductive) strategy on the land use management, a machine learning methodology (Random Forest) is going to be applied to try to relate the main climatic variables (explanatory variables) with the variation of the percentage of irrigated surface (explained variable). In addition, we added a non-climatic variable to the model, the previous percentage of irrigated land, representing the previous state of the area. This is an important variable, as it could show how the evolution of the land use could be more related to an established and profitable industry in a given area, tending to grow more and more, independent from the water availability, rather than

TABLE 4 Main descriptive statistics of the climatic and soil variables.

	Annual rainfall	Annual rainfall's tau	Rainfall day's tau	Wilting point's tau
Mean	369.8927	−0.0983	−0.1436	−0.0633
Median	335.5107	−0.1021	−0.1479	−0.0646
Std	170.3387	0.1127	0.0984	0.1125
Min	125.1481	−0.4031	−0.3597	−0.3723
Max	815.8393	0.1323	0.1182	0.2369

TABLE 5 Correlation matrix among the climatic and soil variables.

Correlation matrix	Annual rainfall's tau	Rainfall days's tau	Wilting point's tau
Annual rainfall	−.1961	−.4739	−.1456
Annual rainfall's Tau		.4026	.7313
Rainfall day's Tau			.4491

being related to the changes in the climatic conditions. So, we will use a Random Forest method to relate the following features with the variation of the percentage of irrigated surface:

- Annual rainfall.
- Annual rainfall variation.
- Rainy days variation.
- Distance to wilting point variation.
- Previous percentage of irrigated land.

To test the validity of the results, the same problem is going to be solved also with the other four accepted machine learning methods, in order to compare precision and results and to confirm the independence of the model for the conclusions. This is, four other machine learning methods are going to be used to try to relate the main climatic variables (plus the previous percentage of irrigated land) with the variation of the percentage of irrigated surface to establish the relation among them and compare with the variable importance measure of the Random Forest method. These four extra machine learning are:

- Multiple regression -ordinary least-squares (MLR-OLS).
- Support Vector Machine for regression.
- Lasso*-LARS: A Lasso (least absolute shrinkage and selection operator) model fit with Least Angle Regression Linkage.
- Bayesian ridge regression.

The whole data set is split into a training set (80% of the items) and a test set (20% of the items), all the models are applied to the training set and tested on the test set. Table 6 includes the mean squared error of all of them:

This table shows how the most precise method is Random Forest, so the most supported conclusions. To establish these conclusions, Table 7 includes the variable importance of each feature according to Random Forest, as well as the coefficients for each variable according to the rest of the methods. For the four methods that are not reporting directly the variable importance (all but Random Forest: MLR-OLS, SVM, Lasso-LARS and Bayesian regression), we are going to consider the coefficient assigned to each variable by each method to measure its importance. All the variables but the first, annual rainfall, are on the same scale: below one in absolute value. So for all of them, the coefficients in the regression methods are comparable, and we can assume that the higher the coefficient of a variable in these regressions, the more important the variable is. The annual rainfall is on a different scale, but the value is so close among all the methods, and negative in all the cases. So, we can assume that the less annual rainfall, the higher the increase in the irrigated land uses for all the regression models.

For the Random Forest method, the only method reporting directly the importance of the variables, the more important, in decreasing order, are previous percentage of irrigated land (0.6052), annual rainfall variation (0.1841) and annual rainfall (0.1127). This information is also confirmed by the multi-lineal regression, MLR-OLS, where these are the only three significative coefficients of the variables. On the contrary, for the Lasso-LARS (a multi-lineal regression forcing the maximum number of coefficients to be zero) the only non-zero coefficients are again previous percentage of irrigated land, annual rainfall variation and annual rainfall. For the SVM model and the Bayesian regression, which do not report importance or significance on the variables, the coefficient of the annual rainfall and the previous percentage of irrigated land is almost the same as for the other models. So, joining the information on the variable relevance for all the models, we can conclude that the most relevant variables are, in this order:

- previous percentage of irrigation land (the more, the more). Strong correlation.
- Annual rainfall variation (the more decrease, the more increase). Medium correlation.
- Annual rainfall (the more, the less). Weaker correlation.

This is confirmed also by observing the correlation coefficients of the variation of the percentage of irrigated land with the rest of the variables (shown in Table 8), where the highest correlations are found also on these same three variables, annual rainfall, annual rainfall variation and previous percentage of irrigated land.

To sum up the results, the most important feature of the increase in the irrigated surface is not a climate feature, but the previous concentration of irrigated land. Areas where many irrigated crops already exist tend to increase their (already big) surface of irrigated crops, independently of the changing climatological conditions, whose general trend is, on the contrary, a decrease in the available water for irrigation. This is because some areas tend to increase their irrigated land surface due to economic reasons, independently of the changing climate. In contrast, the irrigated land surface is also being increased where the annual rainfall is low and/or decreasing, this is due to (changing) climate conditions, but these correlations are weaker than the economic correlation and are always negative. That is, where there is less rainfall there is more irrigated surface, so the water deficit is also increasing, not decreasing. If you are in an area where the surface of irrigated land is high, it will be increased, due to economical reasons. And if you are in an area where there is less

TABLE 6 Mean squared error of the models applied over the test set.

Method	MSE
Random forest	**2.96**
MLR-OLS	5.37
SVM Regr	5.67
Lasso-LARS	5.45
Bayesian reg	5.58

Optimal values are shown in bold.

TABLE 7 Variable importance according to the models applied.

		Coeffic.			
Variable importance	**Random forest**	**MLR-OLS**	**SVM regr.**	**Lasso-LARS**	**Bayesian regr.**
Annual rainfall	0.1127	**−.0078*** **	−.0079	−.0082	−.0079
Annual rainfall variation	0.1841	**−7.2845** **	−2.4389	−5.7007	−2.4221
Rainy days variation	0.0441	2.6522	2.4148	0	.3015
Distance to wilting point variation	0.0539	−.9604	−5.7226	0	−1.4421
Previous % of irrigated land	0.6052	**1.2346*** **	1.3668	1.2343	1.2682

Note: Grey value is not statistically significant. Significance level: *** p-value < 0.01; ** p-value < 0.05. Optimal values are shown in bold.

TABLE 8 Correlation coefficients of the variation of the percentage of irrigated land with the rest of the variables.

Annual rainfall	Annual rainfall variation	Rainy days variation	Distance to wilting point variation	Previous % of irrigated land
−.2319	−.3657	−.1053	−.1995	.8052

rain, the surface of irrigated land will be increased too. So, in both cases, the demand for water resources will be increased in an area where there is no increase or there is a decrease in the water resources.

4 | DISCUSSION

As mentioned in Section 2, in this work we try to demonstrate how the dynamics of changes in land use are evolving without considering the available resources, specifically the availability of water (Vila-Traver et al., 2021) and the soil conditions in a context of extreme climatic situations happening in a changing climate environment. In our opinion, a scientific contribution is needed to demonstrate the relationship between changes in land use and the evolution of climatic factors, and to this aim, we proposed a methodological approach that was resumed in Figure 1.

Several authors have made their contributions in this regard, as Roger and Pielke (2005) and Feddema et al. (2005), where they already showed the relationships between the dynamics of land use and climate change, simulating various scenarios of changes in land use according to variations in climatic conditions. After the first evidences, it was necessary to clarify the different consequences on the territories of the new conditions. In recent decades, the damage caused by weather events has increased dramatically and ubiquitously. In Europe, in general, and in Mediterranean countries in particular, climatic catastrophes are a determining factor in changes in land use and the deterioration of ecosystems (Kron et al., 2019). Our study has been applied in the Mediterranean context of southern Spain. A geographical space in which extreme climatic conditions are fully demonstrated, as evidenced by the works of Lorenzo and Alvarez (2022), Herrera et al. (2010), Vicente-Serrano et al. (2017), Machado et al. (2011) or Furió and Meneu (2011).

Several studies have been developed using different methodologies to identify the emerging patterns of different land use change processes with the information layers used in this study. There is abundant scientific literature addressing the relationship between land use changes and climate change studies (Gallardo, 2018; Titeux et al., 2017).

Relating the quality and validity of the data used to measure the land use changes, various studies have also been published since 1987 in monitoring land use changes in the geographical area under study in this work, having generated abundant information over time about the distribution of land uses and vegetation cover. Since that year, when the European Union's CORINE-Land Cover Program was developed in Spain, with the aim of creating a European-wide Land Cover Map at a 1:100,000 scale, successive projects have been initiated to create and update information on land uses and vegetation cover in the study area. This study starts from one of the first sources of such information, and the land use layer from 1991 has been obtained from this source. Other studies have used these data sources on different dates, as well as other related, among which we can cite (Bermejo & Moreira, 2011; Ojeda & Villar, 2007; Rodrigo-Comino et al., 2014; Romero-Romero et al., 2016; Vila-García et al., 2015). So the accuracy and validity of the data on the land use changes used in this paper are widely contrasted.

In contrast, the Kendall's Tau coefficient is widely used in the field of environmental research and, especially, in the area of climatology. It is frequently used to detect trends in a dataset (Baig et al., 2021), as it was done in the present research. In the Mediterranean region, it is especially interesting to implement this type of statistical analysis, since climate projections and future scenarios of climate change point this region as one of the most uncertain (IPCC, 2021). Thus, consistent with this analysis, a practically generalized worsening has been shown in the three variables evaluated for the Andalusian Mediterranean watershed. This fact is a faithful reflection of the existing situation in this region, where water risks and water scarcity are conceived as one of the main problems facing society (Garrote, 2017; IPCC, 2021; Sordo-Ward et al., 2019).

Besides, following the pattern described by Piccarreta et al. (2013) and Noto et al. (2022, 2023), annual rainfall has experienced a decrease for this Mediterranean area, an evolution that is also followed by the number of rainy days, with a generalized negative Kendall Tau, which, therefore, determines an increase in dry days (Giorgi et al., 2004; Polade et al., 2014). Thus, the reality is that soils are managing less and less water, and the distance to the wilting point of soil is also following a negative trend (Sillero-Medina et al., 2021), with a Tau higher than −0.12 in some cases. So, the system must increasingly adapt to frequent and recurrent conditions of water stress in Mediterranean areas (Lobo Do Vale et al., 2019; Nardini et al. 2014; Noto et al., 2023).

This study of climatic and hydrological dynamics is fundamental since water resources determine a large part of the Mediterranean economy and food security (Noto et al., 2022). Moreover, in a context where a reduction in the availability of fresh water and a high, growing and continuous demand are identified (Fiorillo et al., 2021).

Finally, as a main limitation of the work, we should highlight the intrinsic precision and accuracy limitations of the geostatistical procedures and the regression analyses. Many details on the calibration and validation procedures have been included for this reason, but the quality of the data and precision of the tools applied are always a main aspect and an improvement path in this type of analyses. In the same sense, as a second main limitation on the validity of the results, we cannot exclude that other variables outside the selected in this work could be more related to the land use change patterns, and this fact could also be explored in future research.

5 | CONCLUSIONS

This research has stated, for the Mediterranean region of southern Spain, the existence of a dynamic of changes in land use that is not motivated or related to the availability of green water resources, and that is even in the opposite direction. The results obtained in the analysis of the climatic and hydrological variables (annual rainfall, number of rainy days and distance to the wilting point) show a generalised situation for the study area of great concern. We can identify areas showing a significant decrease in their water resources but where the growth of irrigated crops has been increased.

Under these conditions of considerable water fragility and in a context of climate crisis, in the last 30 years the areas dedicated to irrigated crops have increased by more than 150,000 hectares, currently occupying more than 12% of the surface of the entire Andalusian Mediterranean basin. Thus, in order to determine which have been the most significant and explanatory variables in these changes in land use, an artificial intelligence algorithm (Random Forest) has been used, identifying that the reduction in water availability in different areas is not motivating a reduction in irrigated crops, but the main dynamic being just the opposite, the economic perspective has a preponderant role in the current dynamics of uses. Finally, this information on the most relevant variables on the dynamic of the land use changes is also confirmed by other four models, a MLR-OLS multi-lineal regression, a support vector machine model, a Lasso-LARS regression and a Bayesian ridge regression, all of them confirming a concerning fact: we can find an increase in the irrigated surface in areas with a higher water scarcity.

ACKNOWLEDGEMENTS

This work is part of two projects: (1) 'Effects of land use changes on eco-geomorphological dynamics in Mediterranean environments, at different scales, in the context of Global Change (ECUDES)' (PID2019-104046RB-100) funded by the Ministry of Economy and Competitiveness (MINECO); and (2) the TED-2021-129664B-C22 research project coordinated by the Mayora-CSIC (Ministerio de Ciencia e Innovación, Spain). Part of this research was possible thanks to funding obtained from the University of Malaga, through the I Plan Propio de Investigación, Transferencia y Divulgación Científica. Funding for open access charge: Universidad de Málaga/CBUA.

CONFLICT OF INTEREST STATEMENT

Authors declare that they have no competing financial interests or known personal relationships that could have influenced the work reported in this paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID

J. A. Sillero-Medina https://orcid.org/0000-0002-7856-3239
F. B. Galacho-Jimenez https://orcid.org/0000-0003-0355-2719
J. Molina https://orcid.org/0000-0002-1006-875X
J. D. Ruiz-Sinoga https://orcid.org/0000-0002-2303-0881

REFERENCES

Antonelli, M., Basile, L., Gagliardi, F. & Isernia, P. (2022) The future of the Mediterranean agri-food systems: Trends and perspectives from a Delphi survey. *Land Use Policy*, 120, 106263. Available from: https://doi.org/10.1016/j.landusepol.2022.106263

Baig, M.R.I., Shahfahad, Naikoo, M.W., Ansari, A.H., Ahmad, S. & Rahman, A. (2021) Spatio-temporal analysis of precipitation pattern and trend using standardized precipitation index and Mann–Kendall test in coastal Andhra Pradesh. *Modeling Earth Systems and Environment*, 8(2), 2733–2752. Available from: https://doi.org/10.1007/s40808-021-01262-w

Beilin, R., Lindborg, R., Stenseke, M., Pereira, H.M., Llausàs, A., Slätmo, E. et al. (2012) Analysing how drivers of agricultural land abandonment affect biodiversity and cultural landscapes using case studies from Scandinavia, Iberia and Oceania. *Land Use Policy*, 36, 60–72. Available from: https://doi.org/10.1016/j.landusepol.2013.07.003

Bermejo, D. & Moreira, J.M. (2011) *Half a century of changes in the evolution of land use in Andalusia. 1956–2007*. Sevilla: Consejería de Medio Ambiente. Junta de Andalucía. ISBN: 978-84-92807-67-3.

Breiman, L. (2001) Random forests. *Machine Learning*, 45, 5–32. Available from: https://doi.org/10.1023/A:1010933404324

Calvo-Cases, A., Arnau-Rosalén, E., Boix-Fayos, C., Estrany, J., Roxo, M.J. & Symeonakis, E. (2021) Eco-geomorphological connectivity and coupling interactions at hillslope scale in drylands: Concepts and critical examples. *Journal of Arid Environments*, 186, 104418. Available from: https://doi.org/10.1016/j.jaridenv.2020.104418

Campos, I., González-Piqueras, J., Carrara, A., Villodre, J. & Calera, A. (2016) Estimation of total available water in the soil layer by integrating actual evapotranspiration data in a remote sensing-driven soil water balance. *Journal of Hydrology*, 534, 427–439. Available from: https://doi.org/10.1016/j.jhydrol.2016.01.023

Caparrós-Martínez, J.L., Rueda-Lópe, N., Milán-García, J. & de Pablo Valenciano, J. (2020) Public policies for sustainability and water security: The case of Almeria (Spain). *Global Ecology and Conservation*, 23, 1–17. Available from: https://doi.org/10.1016/j.gecco.2020.e01037

Capone, R., Fersino, V., Stamataki, E., Cerezo, M., Kessari, M., Dernini, S. et al. (2021) Sustainability of food systems in the Mediterranean Region. *New Medit*, 20(3), 131–143. Available from: https://doi.org/10.30682/nmsi21i

Casas, J., Bonachela, S., Moyano, F., Fenoy, E. & Hernández, J. (2015) Agricultural practices in the Mediterranean: A case study in southern Spain. In: Preedy, V.R. & Watson, R.R. (Eds.) *The Mediterranean diet: An evidence-based approach*, Vol. 1, 2nd edition. Academic Press, pp. 23–36. Available from: https://doi.org/10.1016/B978-0-12-407849-9.00003-8

Corbelle, E., Crecente, R. & Santé, I. (2012) Multi-scale assessment and spatial modelling of agricultural land abandonment in a European peripheral region: Galicia (Spain), 1956-2004. *Land Use Policy*, 29, 493–501. Available from: https://doi.org/10.1016/j.landusepol.2011.08.008

Criado, M., Santos-Francés, F., Martínez-Graña, A., Sánchez, Y. & Merchán, L. (2020) Multitemporal analysis of soil sealing and land use changes linked to urban expansion of Salamanca (Spain) using Landsat images and soil carbon management as a mitigating tool for climate change. *Remote Sensing*, 12, 1131. Available from: https://doi.org/10.3390/rs12071131

Cui, F., Wang, B., Zhang, Q., Tang, H., De Maeyer, P.H., Hamdi, R. et al. (2021) Climate change versus land-use change–What affects the ecosystem services more in the forest-steppe ecotone? *Science of the Total Environment*, 759, 143525. Available from: https://doi.org/10.1016/j.scitotenv.2020.143525

Damián, D.A., Márquez, C.O., García, V.J., Rodríguez, M.V. & Recalde, C.G. (2018) Systematic transitions in land use and land cover in a high Andean micro-basin, Ecuador 1991–2011. *Espacios Magazine*, 39(32), 8–20.

Daneshi, A., Brouwer, R., Najafinejad, A., Panahi, M., Zarandian, A. & Maghsood, F.F. (2021) Modelling the impacts of climate and land use change on water security in a semi-arid forested watershed using InVEST. *Journal of Hydrology*, 593, 125621. Available from: https://doi.org/10.1016/j.jhydrol.2020.125621

Duarte, R., Pinilla, V. & Serrano, A. (2021) The globalization of Mediterranean agriculture: A long-term view of the impact on water consumption. *Ecological Economics*, 183, 106964. Available from: https://doi.org/10.1016/j.ecolecon.2021.106964

Fader, M., Shi, S., Von Bloh, W., Bondeau, A. & Cramer, W. (2016) Mediterranean irrigation under climate change: More efficient irrigation needed to compensate forincreases in irrigation water requirements. *Hydrology and Earth System Sciences*, 20, 953–973. Available from: https://doi.org/10.5194/hess-20-953-2016

Farfán, M., Rodríguez-Tapia, G. & Mas, J.F. (2016) Hierarchical analysis of the intensity of land cover/land use change and deforestation (2000–2008) in the sierra de Manantlán biosphere reserve, México. *Investigaciones Geográficas*, 90, 89–104. Available from: https://doi.org/10.14350/rig.48600

Feddema, J.J., Oleson, K.W., Gordon, B.B., Mearns, L.O., Buja, L., Meehl, G.A. et al. (2005) The importance of land-cover change in simulating future climates. *Science*, 310(5754), 1674–1678. Available from: https://doi.org/10.1126/science.1118160

Fernández, R.J. & Trillo, N. (2005) Soil texture as a source of heterogeneity, its effects on the supply of water for plants. In: Oesterheld, M., Aguiar, M.R., Ghersa, C.M. & Paruelo, J.M. (Eds.) *The heterogeneity of the vegetation of agroecosystems*. Buenos Aires: Fac. Agronomy Univ. Buenos Aires, pp. 171–192.

Ferrara, A., Salvati, L., Sabbi, A. & Colantoni, A. (2014) Soil resources, land cover changes and rural areas: Towards a spatial mismatch? *Science of the Total Environment*, 478, 116–122. Available from: https://doi.org/10.1016/j.scitotenv.2014.01.040

Fiorillo, D., Kapelan, Z., Xenochristou, M., De Paola, F. & Giugni, M. (2021) Assessing the impact of climate change on future water demand using weather data. *Water Resources Management*, 35(5), 1449–1462. Available from: https://doi.org/10.1007/s11269-021-02789-4

Furió, D. & Meneu, V. (2011) Analysis of extreme temperatures for four sites across peninsular Spain. *Theoretical and Applied Climatology*, 104, 83–99. Available from: https://doi.org/10.1007/s00704-010-0324-5

Gabarrón-Galeote, M.A., Ruiz-Sinoga, J.D. & Quesada, M.A. (2013) Influence of aspect in soil and vegetation water dynamics in dry Mediterranean conditions: Functional adjustment of evergreen and semi-deciduous growth forms. *Ecohydrology*, 6, 241–255. Available from: https://doi.org/10.1002/eco.1262

Galacho-Jiménez, F.B. & Reyes-Corredera, S. (2024) Spatial analysis model for the evaluation of the territorial adequacy of the urban process in coastal areas. *Land*, 13(1), 109. Available from: https://doi.org/10.3390/land13010109

Gallardo, M. (2018) Review and analysis of studies of land-use change models and future scenarios. *Geographical*, 70, 1–26. Available from: https://doi.org/10.26754/ojs_geoph/geoph.2018703278

García-Marín, R., Espejo-Marín, C., Giménez-García, R. & Ruiz-Álvarez, V. (2020) Transformations in the agricultural and scenic landscapes in the northwest of the region of Murcia (Spain): Moving towards long awaited (un)sustainability. *Land*, 9, 314. Available from: https://doi.org/10.3390/land9090314

Garrote, L. (2017) Managing water resources to adapt to climate change: facing uncertainty and scarcity in a changing context. *Water Resources Management*, 31(10), 2951–2963. Available from: https://doi.org/10.1007/s11269-017-1714-6

Giannakopoulos, C., Le Sager, P., Bindi, M., Moriondo, M., Kostopoulou, E. & Goodess, C.M. (2009) Climatic changes and associated impacts in the Mediterranean resulting from a 2°C global warming. *Global and Planetary Change*, 68(3), 209–224. Available from: https://doi.org/10.1016/j.gloplacha.2009.06.001

Giorgi, F., Bi, X. & Pal, J. (2004) Mean, interannual variability and trends in a regional climate change experiment over Europe. II: climate change scenarios (2071 2100). *Climate Dynamics*, 23(7–8), 839–858. Available from: https://doi.org/10.1007/s00382-004-0467-0

Grabska-Szwagrzyk, E., Khiabani, P.H., Pesoa-Marcilla, M., Chaturvedi, V. & De Vries, W.T. (2024) Exploring land use dynamics in rural areas. An analysis of eight cases in the global north. *Land Use Policy*, 144, 107246. Available from: https://doi.org/10.1016/j.landusepol.2024.107246

Hamacara, L., Buzai, G. & Lara, B. (2019) Mapping of land use changes. Development and analysis based on geographic information systems. *Geographic Paragraphs*, 18(1), 22–43.

Haregeweyna, N., Fikadub, G., Tsunekawaa, A., Tsuboa, M. & Mesheshaa, D.T. (2012) The dynamics of urban expansion and its impacts on land use/land cover change and small-scale farmers living near the urban fringe: A case study of Bahir Dar, Ethiopia. *Landscape and Urban Planning*, 106, 149–157. Available from: https://doi.org/10.1016/j.landurbplan.2012.02.016

Hasan, S.S., Zhen, L., Miah, M.G., Ahamed, T. & Samie, A. (2020) Impact of land use change on ecosystem services: A review. *Environmental Development*, 34, 100527. Available from: https://doi.org/10.1016/j.envdev.2020.100527

Herrera, S., Fita, L., Fernandez, J. & Gutierrez, J.M. (2010) Evaluation of the mean and extreme precipitation regimes from the ENSEMBLES regional climate multimodel simulations over Spain. *Journal of Geophysical Research*, 115, D21117. Available from: https://doi.org/10.1029/2010JD013936

Humacata, L. (2019) Spatial analysis of land use changes. Application with geographic information systems. *Cartographic Review*, 98, 239–257. Available from: https://doi.org/10.35424/rcarto.i98.149

IPCC (Intergovernmental Panel on Climate Change). (2021) Climate change 2021: The physical science basis (Contribution of Working Group I to the Sixth Assessment Report).

Jiménez-Olivencia, Y., Ibáñez-Jiménez, Á., Porcel-Rodríguez, L. & Zimmerer, K. (2021) Land use change dynamics in euro-mediterranean mountain regions: Driving forces and consequences for the landscape. *Land Use Policy*, 109, 105721. Available from: https://doi.org/10.1016/j.landusepol.2021.105721

Kirkham, M.B. (2005) Field capacity, wilting point, available water, and the non-limiting water range. In: Kirkham, M.B. (Ed.) *Principles of soil and plant water relations*. Burlington: Academic Press, pp. 101–115. Available from: https://doi.org/10.1016/B978-012409751-3/50008-6

Kron, W., Eichner, J. & Kundzewicz, Z.W. (2019) Reduction of flood risk in Europe – Reflections from a reinsurance perspective. *Journal of Hydrology*, 576, 197–209. Available from: https://doi.org/10.1016/j.jhydrol.2019.06.050

Kunkel, K.E., Andsager, K. & Easterling, D.R. (1999) Long term trends in extreme precipitation events over United States and Canada. *Journal of Climate*, 12, 2515–2527. Available from: https://doi.org/10.1175/1520-0442(1999)012<2515:LTTIEP>2.0.CO,2

Laio, F., Porporato, A., Ridolfi, L. & Rodriguez-Iturbe, I. (2001) Plants in water-controlled ecosystems: Active role in hydrologic processes and response to water stress: II. Probabilistic soil moisture dynamics. *Advances in Water Resources*, 24(7), 707–723. Available from: https://doi.org/10.1016/S0309-1708(01)00004-5

Lana, X., Martínez, M.D., Burgueño, A., Serra, C., Martín-Vide, J. & Gómez, L. (2008) Spatial and temporal patterns of dry spell lengths in the Iberian Peninsula for the second half of the twentieth century. *Theoretical and Applied Climatology*, 91, 99–116. Available from: https://doi.org/10.1007/s00704-007-0300-x

Lobo-do-Vale, R., Kurz Besson, C., Caldeira, M.C., Chaves, M.M. & Pereira, J.S. (2019) Drought reduces tree growing season length but increases nitrogen resorption efficiency in a Mediterranean ecosystem. *Biogeosciences*, 16(6), 1265–1279. Available from: https://doi.org/10.5194/bg-16-1265-2019

Lorenzo, M.N. & Alvarez, I. (2022) Future changes of hot extremes in Spain: Towards warmer conditions. *Natural Hazards*, 113, 383–402. Available from: https://doi.org/10.1007/s11069-022-05306-x

Luo, Y., Lü, Y., Liua, L., Liang, H., Li, T. & Ren, Y. (2020) Spatiotemporal scale and integrative methods matter for quantifying the driving forces of land cover change. *Science of the Total Environment*, 739, 139622. Available from: https://doi.org/10.1016/j.scitotenv.2020.139622

Machado, M.J., Benito, G., Sweeps, M. & Rodrigo, F.S. (2011) 500 years of rainfall variability and extreme hydrological events in southeastern Spain drylands. *Journal of Arid Environments*, 75(12), 1244–1253. Available from: https://doi.org/10.1016/j.jaridenv.2011.02.002

Martí, P. & García-Mayor, C. (2020) The Huerta agricultural landscape in the Spanish Mediterranean arc: One landscape, two perspectives, three specific huertas. *Land*, 9, 460. Available from: https://doi.org/10.3390/land9110460

Martínez-Fernández, J. (1996) *Spatial variability of the physical and water properties of soils in semi-arid Mediterranean environment*. Murcia: University of Murcia.

Martínez-Fernández, J., Ceballos-Barbancho, A. & Luengo-Ugidos, M.A. (2001) La sequía edáfica en la cuenca del Duero. *Ecosystems*, 10(3).

Meeus, J.H.A., Wijermans, M.P. & Vroom, M.J. (1990) Agricultural landscapes in Europe and their transformation. *Landscape and Urban Planning*, 18(3–4), 289–352. Available from: https://doi.org/10.1016/0169-2046(90)90016-U

Melendez, I., Hernández, J., Navarro, E.I. & Gómez, I. (2014) Socioeconomic factors influencing land cover changes in rural areas: The case of the sierra de Albarracín (Spain). *Applied Geography*, 52, 34–45. Available from: https://doi.org/10.1016/j.apgeog.2014.04.0130

Millán, M. (2014) Extreme hydrometeorological events and climate change predictions in Europe. *Journal of Hydrology*, 518, 206–224. Available from: https://doi.org/10.1016/j.jhydrol.2013.12.041

Moreira-Madueño, J.M. (2006) El sistema de información geográfica-ambiental de Andalucía: Del SINAMBA a la Red de Información Ambiental de Andalucía. *GeoFocus (Recursos)*, 6, 4–10.

Nagendra, H., Munroe, D.K. & Southworth, J. (2004) From pattern to process: Landscape fragmentation and the analysis of land use/land cover change. *Agriculture, Ecosystems and Environment*, 101, 111–115. Available from: https://doi.org/10.1016/j.agee.2003.09.003

Nardini, A., Lo Gullo, M.A., Trifilò, P. & Salleo, S. (2014) The challenge of the Mediterranean climate to plant hydraulics: Responses and adaptations. *Environmental and Experimental Botany*, 103, 68–79. Available from: https://doi.org/10.1016/j.envexpbot.2013.09.018

Negri, D.H., Gollehon, N.R. & Aillery, M.P. (2005) The effects of climatic variability on US irrigation adoption. *Climate Change*, 69, 299–323. Available from: https://doi.org/10.1007/s10584-005-1817-6

Noto, L.V., Cipolla, G., Francipane, A. & Pumo, D. (2022) Climate change in the Mediterranean Basin (Part I): induced alterations on climate forcings and hydrological processes. *Water Resources Management*, 37(6–7), 2287–2305. Available from: https://doi.org/10.1007/s11269-022-03400-0

Noto, L.V., Cipolla, G., Pumo, D. & Francipane, A. (2023) Climate change in the Mediterranean basin (Part II): a review of challenges and uncertainties in climate change modeling and impact analyses. *Water Resources Management*, 37(6–7), 2307–2323. Available from: https://doi.org/10.1007/s11269-023-03444-w

Obiahua, O.E. & Elias, E. (2020) Effect of land use land cover changes on the rate of soil erosion in the upper Eyiohia river catchment of Afikpo north area, Nigeria. *Environmental Challenges*, 1, 100002. Available from: https://doi.org/10.1016/j.envc.2020.100002

Ojeda, J. & Villar, A. (2007) Evolution of urban/altered land on the coast of Andalusia. *GeoFocus*, 7, 73–99.

Piccarreta, M., Pasini, A., Capolongo, D. & Lazzari, M. (2013) Changes in daily precipitation extremes in the Mediterranean from 1951 to 2010: The Basilicata region, southern Italy. *International Journal of Climatology*, 33(13), 3229–3248. Available from: https://doi.org/10.1002/joc.3670

Polade, S.D., Pierce, D.W., Cayan, D.R., Gershunov, A. & Dettinger, M.D. (2014) The key role of dry days in changing regional climate and precipitation regimes. *Scientific Reports*, 4(1), 4364. Available from: https://doi.org/10.1038/srep04364

Pontius, R.G., Shusas, E. & McEchern, M. (2004) Detecting important categorical land changes while accounting for persistence. *Agriculture, Ecosystems and Environment*, 101(2–3), 251–268. Available from: https://doi.org/10.1016/j.agee.2003.09.008

Pérez, U. & Bosque, J. (2008) Land cover and use transitions in the period 1991–2005 in the Combeima river basin (Colombia). *Geographic Series*, 14, 163–178.

Rodrigo-Comino, J., Senciales-González, J.M. & Ferré Bueno, E. (2014) Análisis de los cambios de usos del suelo en el área de Casapalma (Valle del Guadalhorce, Málaga) entre 1991 y 2007. *Papeles de Geografía*, 59-60, 157–171. Available from: https://doi.org/10.6018/geografia/2014/218221

Roger, T. & Pielke, S.R. (2005) Land use and climate change. *Science*, 310(5754), 1625–1626. Available from: https://doi.org/10.1126/science.1120529

Romero-Romero, D., Romero-Morato, A., Guerrero-Álvarez, J.J., Giménez-De-Azcarate, F., Cáceres-Clavero, F. & Moreira-Madueño, J.M. (2016) Comparative analysis between the distribution of land uses in Andalusia and its visual accessibility. *Rediam GeoFocus*, 20, 63–85. Available from: https://doi.org/10.21138/GF.516

Rossi, G. (2015) Achieving ethical responsibilities in water management: A challenge. *Agricultural Water Management*, 147, 96–102. Available from: https://doi.org/10.1016/j.agwat.2014.07.030

Ruiz, I. & Sanz-Sánchez, M.J. (2020) Effects of historical land-use change in the Mediterranean environment. *Science of the Total Environment*, 732, 139315. Available from: https://doi.org/10.1016/j.scitotenv.2020.139315

Ruiz-Sinoga, J.D. & Romero-Diaz, A. (2010) Soil degradation factors along a Mediterranean pluviometric gradient in southern Spain. *Geomorphology*, 118(3–118), 359–368. Available from: https://doi.org/10.1016/j.geomorph.2010.02.003

Ruiz-Sinoga, J.D., Gabarrón-Galeote, M.A., Martínez-Murillo, J.F. & García- Marín, R. (2011) Vegetation strategies for soil water consumption along a pluviometric gradient in southern Spain. *Catena*, 84, 12–20. Available from: https://doi.org/10.1016/j.catena.2010.08.011

Ruiz-Sinoga, J.D., Martínez-Murillo, J.F., Gabarrón-Galeote, M.A. & García- Marín, R. (2010a) The effects of soil moisture variability on the vegetation pattern in Mediterranean abandoned fields (southern Spain). *Catena*, 85(1), 1–11. Available from: https://doi.org/10.1016/j.catena.2010.11.004

Ruiz-Sinoga, J.D., Romero-Diaz, A., Ferre-Bueno, E. & Martínez-Murillo, J.F. (2010b) The role of soil surface conditions in regulating runoff and erosion processes on a metamorphic hillslope (southern Spain). Soilsurface conditions, runoff and erosion in southern Spain. *Catena*, 80(2), 131–139. Available from: https://doi.org/10.1016/j.catena.2009.09.007

Saadi, S., Todorovic, M., Tanasijevic, L., Pereira, L.S., Pizzigalli, C. & Lionello, P. (2015) Climate change and Mediterranean agriculture: Impacts on winter wheat and tomato crop evapotranspiration, irrigation requirements and yield. *Agricultural Water Management*, 147, 103–115. Available from: https://doi.org/10.1016/j.agwat.2014.05.008

Serra, P., Pons, X. & Saurí, D. (2008) Land-cover and land-use change in a Mediterranean landscape: A spatial analysis of driving forces integrating biophysical and human factors. *Applied Geography*, 28(3), 189–209. Available from: https://doi.org/10.1016/j.apgeog.2008.02.001

Serrano, A., Pinilla, V. & Duarte, R. (2022) A grandes transformaciones agrarias, grandes impactos hídricos: Un análisis histórico del consumo agrario de agua en España. *Sociedad Española de Historia Agraria*, 2202, 73–93.

Sillero-Medina, J.A., Rodrigo-Comino, J. & Ruiz-Sinoga, J.D. (2021) Factors determining the soil available water during the last two decades (1997–2019) in southern Spain. *Arabian Journal of Geosciences*, 14, 1971. Available from: https://doi.org/10.1007/s12517-021-08265-y

Slaymaker, O., Pencer, T. & Dadson, S. (2009) Landscape and landscape-scale processes as the unfilled niche in the global environmental change debate: An introduction. In: Slaymaker, O., Spencer, T. & Embleton-Hamann, C. (Eds.) *Geomorphology and global environmental change*, Vol. 2, 2nd edition. Cambridge: Cambridge University Press, pp. 1–36. Available from: https://doi.org/10.1017/CBO9780511627057.002

Song, W. & Liu, M. (2014) Assessment of decoupling between rural settlement area and rural population in China. *Land Use Policy*, 39, 331–341. Available from: https://doi.org/10.1016/j.landusepol.2014.02.002

Sordo-Ward, A., Granados, A., Iglesias, A., Garrote, L. & Bejarano, M. (2019) Adaptation effort and performance of water management strategies to face climate change impacts in six representative basins of Southern Europe. *Water*, 11(5), 1078. Available from: https://doi.org/10.3390/w11051078

Sun, Q., Qi, W. & Yu, X. (2021) Impacts of land use change on ecosystem services in the intensive agricultural area of North China based on multi-scenario analysis. *Alexandria Engineering Journal*, 60, 1703–1716. Available from: https://doi.org/10.1016/j.aej.2020.11.020

Tadese, M., Kumar, L., Koech, R. & Kogo, B.K. (2020) Mapping of land-use/land-cover changes and its dynamics in Awash River basin using remote sensing and GIS. *Remote Sensing Applications: Society and Environment*, 19, 100352. Available from: https://doi.org/10.1016/j.rsase.2020.100352

Titeux, N., Henle, K., Mihoub, J.B., Regos, A., Geizendorffer, I.R., Cramer, W. et al. (2017) Global scenarios for biodiversity need to better integrate climate and land use change. *Diversity and Distributions*, 23(11), 1231–1234. Available from: https://doi.org/10.1111/ddi.12624

Tomaz, C., Alegria, C., Massano, J. & Canavarro, M. (2013) Land cover change and afforestation of marginal and abandoned agricultural land: A 10 year analysis in a Mediterranean region. *Forest Ecology and Management*, 308, 40–49. Available from: https://doi.org/10.1016/j.foreco.2013.07.044

Vicente-Serrano, S.M., Rodriguez-Camino, A., Dominguez-Castro, F., El Kenawy, A.M. & Azorín-Molina, C. (2017) An updated review on recent trends in observational surface atmospheric variables and their extremes over Spain. *Geographical Research Letters*, 43(1), 209–232. Available from: https://doi.org/10.18172/cig.3134

Vila-García, D., Gil-Docampo, M.L. & Iniesto-Alba, M.J. (2015) Change detection in land use from unsupervised classifications for updating SIOSE. Implementation in Galicia. *Revista de Teledetección*, 43, 63–75. Available from: https://doi.org/10.4995/raet.2015.3409

Vila-Traver, J., Aguilera, E., Infante-Amate, J. & González de Molina, M. (2021) Climate change and industrialization as the main drivers of Spanish agriculture water stress. *Science of the Total Environment*, 760, 143399. Available from: https://doi.org/10.1016/j.scitotenv.2020.143399

Zhang, X., Zwiers, F.W. & Li, G. (2004) Monte Carlo experiments on the detection of trends in extreme values. *Journal of Climate*, 17, 1945–1952. Available from: https://doi.org/10.1175/1520-0442(2004)017<1945:MCEOTD>2.0.CO,2

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Figures S1-S3.

How to cite this article: Sillero-Medina, J.A., Galacho-Jimenez, F.B., Molina, J. & Ruiz-Sinoga, J.D. (2024) Analysis of the dynamics of the land use changes in the Mediterranean region of southern Spain and its relationship with water availability. *Geo: Geography and Environment*, 11, e00161. Available from: https://doi.org/10.1002/geo2.161