

Method Article

Classification of Mediterranean hedgerows: A methodological approximation

Fernando Allende Alvarez*, Gillian Gomez-Mediavilla,
Nieves López-Estébanez, Pedro Molina Holgado

Geography Department, Universidad Autónoma de Madrid, Spain



ABSTRACT

The present paper addresses the methodology carried out to obtain a new classification of hedgerow networks in the Mediterranean region using GIS and Remote Sensing. A new methodology has been developed due to the need to establish a typification of the hedgerows in this sector of southern Europe, where the variable conditioning the localization, area and type of these landscapes is degree of surface soil moisture. In the continental Mediterranean context, this age-old agricultural system is closely linked to access to, and management of, water resources, which are vital in the dry season. For this reason, we mapped the hedgerow network of a continental Mediterranean mountain, establishing different levels of surface soil moisture provided by images from the satellite *Sentinel-2*. The results render three types of hedgerows: moist, semi-moist and dry, each one presenting clearly differentiated localizations and characteristics. To this can be added the analysis of the evolution of their area from 1956 to the present time from aerial pictures and satellite images and their correlation with surface soil moisture and slope. We present results on this tested method from the central sector of the Iberian Peninsula, Spain.

- The presented procedure focuses on a new classification of hedgerow networks in the Mediterranean region based on the degree of surface soil moisture.
- The method establishes different levels of surface soil moisture provided by images from the satellite *Sentinel-2*.
- The procedure allows us to analyze and correlate the evolution of Mediterranean hedgerows with surface soil moisture.

© 2021 The Authors. Published by Elsevier B.V.
This is an open access article under the CC BY-NC-ND license
(<http://creativecommons.org/licenses/by-nc-nd/4.0/>)

DOI of original article: [10.1016/j.landusepol.2021.105342](https://doi.org/10.1016/j.landusepol.2021.105342)

* Corresponding author.

E-mail address: fernando.allende@uam.es (F.A. Alvarez).

<https://doi.org/10.1016/j.mex.2021.101355>

2215-0161/© 2021 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license
(<http://creativecommons.org/licenses/by-nc-nd/4.0/>)

ARTICLE INFO

Method name: Remote sensing and GIS applicated to hedgerows classification

Keywords: GIS, Remote sensing, Sentinel-2, Hedgerows, Rural landscapes

Article history: Received 15 February 2021; Accepted 11 April 2021; Available online 20 April 2021

Specifications table

Subject Area:	Environmental Science
More specific subject area:	Geography of rural landscape; Biogeography
Method name:	Remote sensing and GIS applicated to hedgerows classification
Name and reference of original method:	Allende Álvarez, F., Gómez Mediavilla, G., López Estébanez, N., 2021. Environmental, demographic and policy drivers of change in mediterranean hedgerow landscape (Central Spain), Land Use Policy,Volume 103, 105,342. (available online)
Resource availability:	No applicable

Method details

Some research in the study area has focused upon the different environmental variables influencing the localization of the hedgerows, among these, soil water content [1,2]. No studies, however, address the relationship between surface soil moisture and the localization of these landscapes. For the reason we attempt to establish a new classification of this agricultural landscape in the Mediterranean region, proposing a typology based upon the parameter conditioning its existence in this sector of southern Europe: degree of surface soil moisture. The next step is to analyze the change of the hedgerow landscape from 1956 to the present time from aerial pictures and satellite images and their correlation with surface soil moisture and slope. The methodology is validated by the study of the central sector of the Guadarrama Mountains and its piedmont, one of southern Europe's most significant areas of continental Mediterranean hedgerows (Fig. 1).

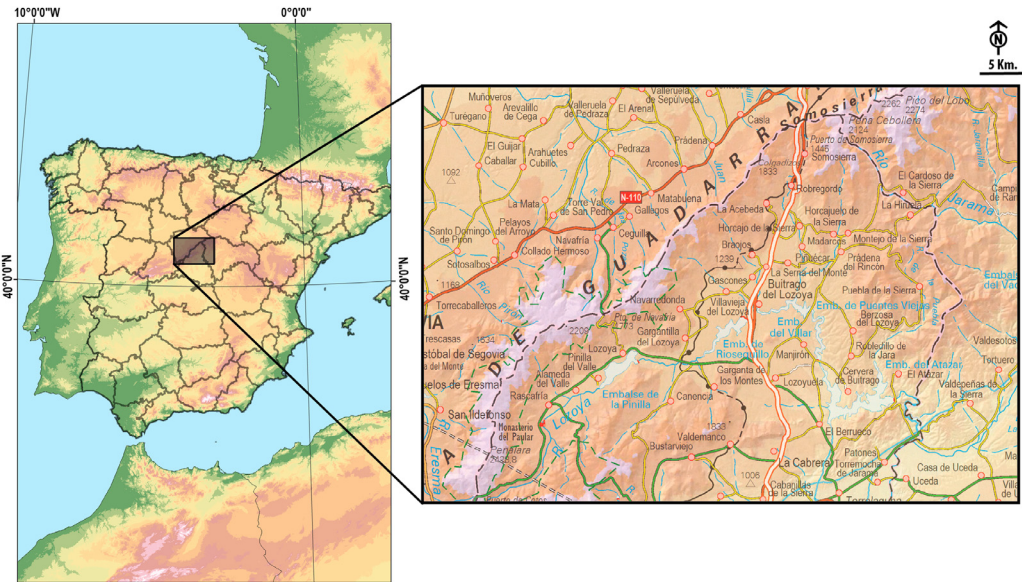


Fig. 1. Study area (Map base source: Spain MDE from USGS Shuttle Radar Topography, 2004 [3]; Topographic information from Spanish National Geographic Institute 1:200,000 [4]).

Arcgis 10.7.1 software (editor)

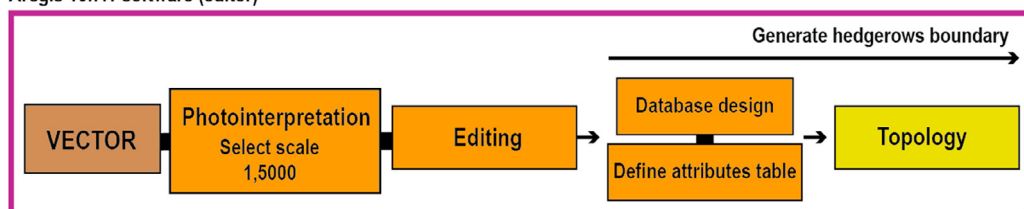


Fig. 2. Define hedgerow area (initial phase).

The methodology was developed in three phases: demarcation and quantification of the area occupied by hedges and urban land in 1956 and at the present time, estimation of the variables most influencing their localization (surface soil moisture and slope) and, lastly, typification thereof. Vector info was processed within Arcgis 10.7.1 software (editor module). For raster Spatial Analyst and Image Analyst modules (Arcgis) were used. Finally, we have analyzed SENTINEL 2 images [5] with ERDAS IMAGINE.

In the initial phase (Fig. 2 y 3) we digitized in shape file format the areas considered to constitute hedgerow networks and urban land at the present time and in 1956. For this, images info was interpreted considering technical features [6–8], interface urban-rural in the mediterranean mountains [9–15] and landscape patterns in Spain [16–18]. This information was photointerpreted at a scale of 1:5000 considering any possible modifications or rectifications of the existing information or any incorporation of new polygons. Finally, all the information was topologically validated. We delimited the hedgerows following a series of criteria among which we considered to be fundamental to include plots presenting a division (hedgerows, hedgerows with trees, trees, or stone walls with hedges and trees, dry stone walls etc.) or those presenting an internal limit without a physical boundary but with a visible external one.

For the urban land we considered the continuity of the built-up area on both dates. We subsequently conducted a verification in the field on predesigned tracks on the LIDAR layer (0.5 m.), available at the National Geographic Institute [19]; on these itineraries we represented the hedgerows presenting different typologies and altitudinal levels. The vectorial information was processed by means of Arcgis 10.7.1 software and the raster with Imagine Analysis by Arcgis. (Fig. 2). As reference digital sources we employed: the *Mapa Forestal de la Comunidad de Madrid* (Forestry Map of the Madrid Regional Autonomy) in *.shp format (Consejería de Medio Ambiente de la CAM- Madrid Regional Autonomy Dept. of the Environment) [20], the Rural Cadastral Registry cartography at a scale of 1:5000 by means of the WMS system (Dirección General del Catastro- General Land Registry) [21], the orthoimage of the Madrid Regional Autonomy from the year 2014 at a scale of 1:5000 (Geoportal de la Infraestructura de Datos Espaciales de la CAM-the Madrid Regional Autonomy Infrastructure Geoportal for Spatial Data) [22], the Madrid Regional Autonomy's Map of spatial occupation at a scale of 1:5000 (Madrid Regional Autonomy) [23] and Series A (1945–1946) and B (1956–1957) from the USAF (United States Air Force) [24], previously georeferenced and mosaicked.

Using the cartography of hedgerow networks and of urbanised land for the two dates, we performed a comparative analysis in which we considered the most representative changes with regard to size, shape and use. This enabled us to quantify the principal change processes (loss or stability in the case of the hedgerows, and increase or stability in the case of the urbanised environments) (Fig. 3).

In the second phase we classified the hedgerows according to surface soil moisture with the use of Sentinel-2 images. In this phase ERDAS IMAGINE and Image Analyst Module (Argis 10.7.1) were used (Fig. 4). To this end we previously selected images available from 2008 to 2015 for the two periods, spring and summer; the final third of spring (May) and the first two thirds of summer (June–July) are of particular relevance. In this seasonal selection we preferentially considered the irrigation needs of the delimited areas, mostly comprising meadows, which enables clearer discrimination. In the case

Arcgis 10.7.1 software (editor)

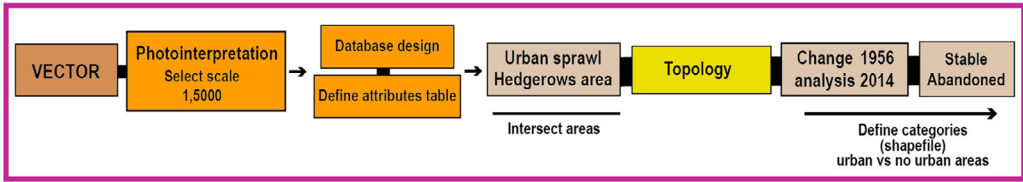


Fig. 3. Define urban sprawl and change categories (initial phase).

Arcgis 10.7.1 software (image analyst) and ERDAS IMAGINE

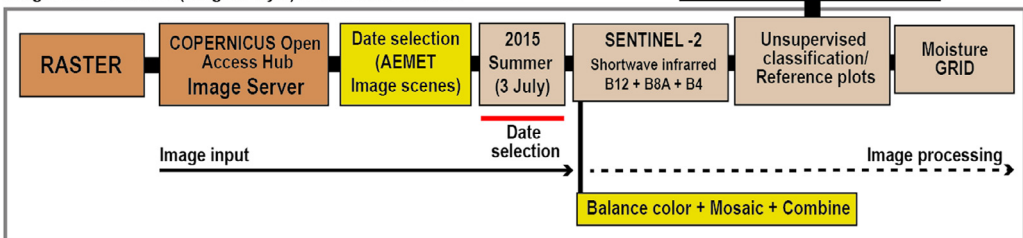


Fig. 4. Image processing (second phase).

of the abandoned zones or the sectors at higher altitudes, the references were surface runoffs or old channels that were partially functional as a result of overflow.

Having defined the reference periods, we eliminated any flyovers with dense cloud cover, deficiencies in data collection or difficult-to-balance chromatic values. The “valid” images were compared with the seasonal summaries of the AEMET (2015) involving the search for years classified as “normal”. In this appraisal we considered the possible dryness resulting from an excessively dry spring or from a very wet summer. The Navacerrada meteorological station was used to characterize the climatic year, since it was the only one that had comparable data for both dates. Precipitation at the Navacerrada station was lower in both years, than the average from historical records (1349.8 mm): 1071 mm (1956), and 1153.14 (2019) [25]. The climatic year accumulated a rainfall deficit, especially in spring, with average rainfall between 288 mm and 203 mm compared to the average of 362.1 mm.

Finally, the only image that complied with a series of characteristics enabling a certain degree of reliability was the one from July 3rd 2015 in a summer considered by the AEMET [25] to be normal-wet ($W = \text{Wet}$: $20\% \leq f < 40\%$. $N = \text{Normal}$: $40\% \leq 60\%$) and in which recorded precipitation was around the median. *Sentinel-2* enabled a combination of bands (EOS DATA ANALYTICS, 2017) at different resolutions (10 m - Near-Infrared bands- and 20 m, Red Edge and shortwave infrared bands), which facilitated discrimination of the different levels of surface soil moisture (near-infrared -12-; Red Edge 8 -8A- and Red -4-) applied to agriculture [26–30], to irrigated fields [31–33] and, more precisely, to pasture [34,35]. The scenes (a total of four) were mosaicked and contrasted with the use of the nearest neighbour method to obtain a final image in GRID format. Due to the volume of resulting information we performed a clip of the image on the area defined as hedgerows for easier handling. Subsequently, to eliminate errors we conducted a test using the *shape file* layer of hedgerows as a reference. On the tracks designed in the initial phase we performed systematic sampling of the sectors in which we had previously ascertained the seasonal variability of the levels of surface soil moisture. We then obtained an unsupervised classification in 6 categories which were simplified in three: moist, semi-moist and dry. We had previously evaluated the inclusion of further categories or reducing them to just these three. In the first case an excessive number of values made no contribution and in the second case, a loss of nuances was generated in the transition between categories, particularly in those exhibiting a greater degree of variability due to the loss of homogeneity on the surface: semi-moist and dry.

Arcgis 10.7.1 software (editor + spatial analyst)

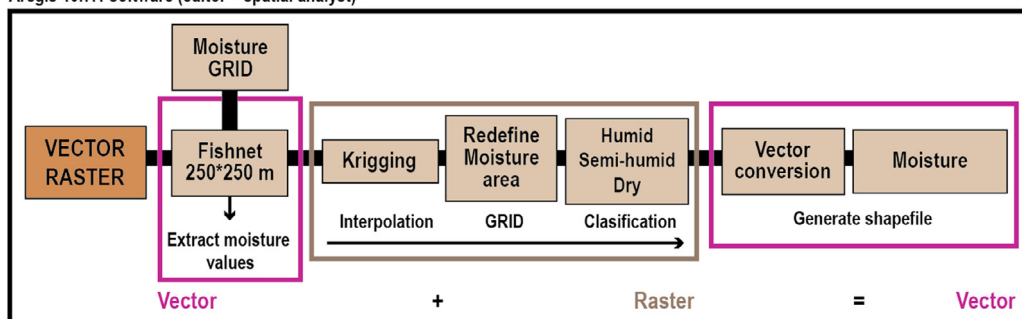


Fig. 5. Image processing (third phase).

Arcgis 10.7.1 (analyst)

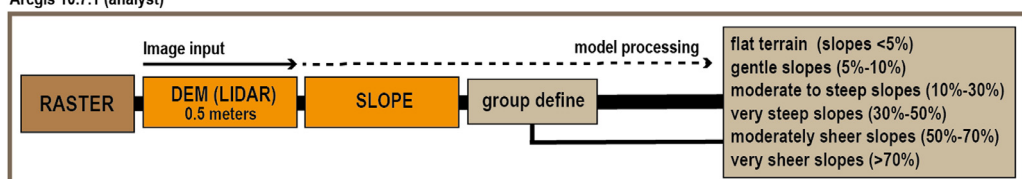


Fig. 6. Slope processing (third phase).

Finally, in the third phase we designed a mesh measuring 250*250 metres covering the whole study area, obtaining the centroids which were subsequently crossed with the categories of moisture (Fig. 5). These centroids were interpolated by means of krigging normally used in GIS studies and applied to estimate soil moisture [36–38], an interpolation system that proves valid when the sample is well distributed [39–41]; this provided cartography of surface soil moisture and an initial classification of the hedgerow networks from SENTINEL-2 [42–45]. In this phase, slopes were calculated and incorporated as the determinant variable in the processes of abandonment or stability in the hedgerow networks (Fig. 6). Some authors consider this factor to be vital for the maintenance or abandonment of agriculture or livestock farming [46–49]. In the calculation we used the slopes calculated in percentages with the LIDAR (0.5 m.) model [50–53], which were grouped into 6 intervals [54]: 1) flat terrain (slopes <5%); 2) gentle slopes (5%–10%); 3) moderate to steep slopes (10%–30%); 4) very steep slopes (30%–50%); 5) moderately sheer slopes (50%–70%); 6) very sheer slopes (>70%).

Method validation

The proposed area for validating the methodology is situated at the southern piedmont of the Guadarrama Mountains, within the central sector of the Iberian Peninsula. The mountain range, running in a northwest-southeast direction, is articulated in a series of raised (2400 m) and sunken (900 - 1000 m) morphostructural blocks presenting intense altitudinal gradients. The relief is generally arranged following a tectonic system of post-alpine reactivation faults, the direction of which conditions the existence of a series of intramontane and longitudinal depressions on the periphery of the dominant reliefs. Running along the foot of the main reliefs are gentle ramps that form a piedmont, which progressively loses height. We divided the area into six groups (49 municipalities), considering its agrological and physiographic characteristics. In this sector, piedmonts alternate with depressions and slopes on granites, upon metamorphic materials and on mixed materials. The climate is of the continental Mediterranean type with hot dry summers, average precipitation slightly higher than 650 mm per year and average temperatures ranging from 12 to 14°C. The strong altitudinal and climatic gradient generated by the mountain range favours the existence of a high degree of bio-

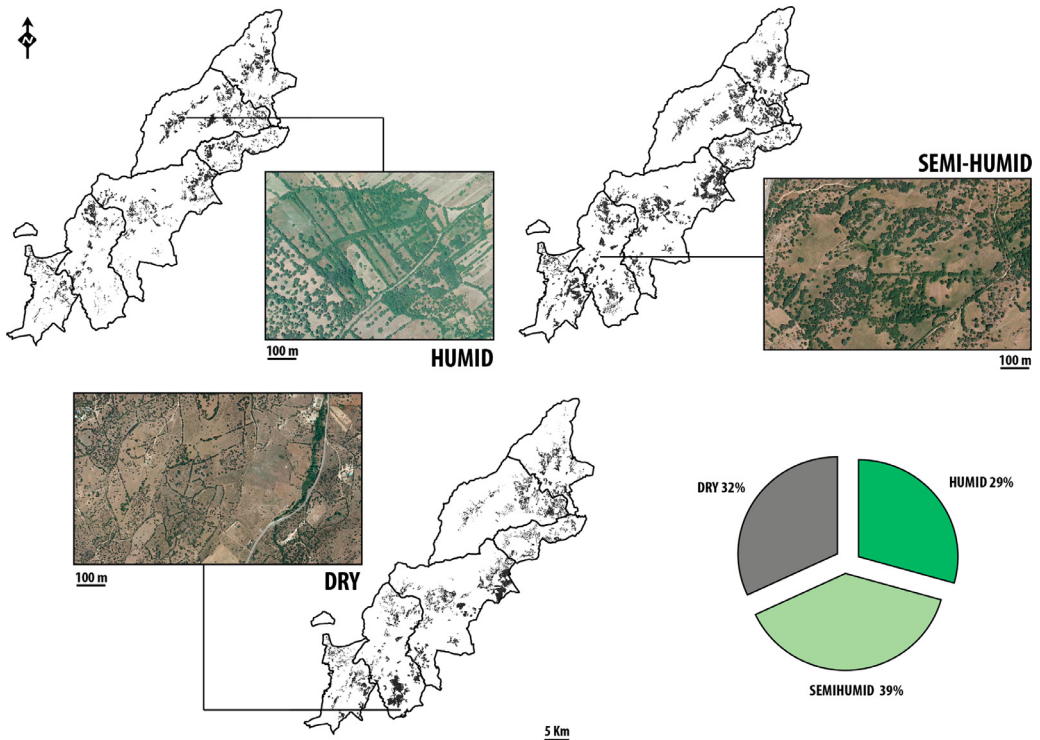


Fig. 7. Distribution and area occupied according to degree of surface soil moisture.

and agro-diversity, with different types of pastures. A long period of summer drought, along with seasonal water resources, are characteristics determining the uniqueness of these hedgerow networks in relation to the Atlantic ones in the north of the peninsula and central Europe, and it is precisely the hydro-climatic conditions that make Guadarrama's hedgerows heterogeneous.

Dependence on water resources: definition of typologies according to surface soil moisture.

As has been pointed out, access to, and management of, water resources is fundamental in the localisation of hedgerows. In the continental Mediterranean context, this agrosystem is associated with the accumulation of water resources in the mountain headwaters and with the proper channelling thereof in the dry season (June-September). In the study area the hedgerow network occupies a total area of 24,400 ha. The results of the analysis of the *Sentinel-2* images provided three categories: moist (7169.12 ha), semi-moist (9428.23 ha) and dry (7803.53 ha) hedgerows (Fig. 7).

The moist hedgerows cover 29.38% of the total and constitute the most productive irrigated agrosystems. The highest concentrations of this category are reached in a specific meadow silvosystem (Lozoya Valley), with 43.98% of hedgerows and a high degree of surface soil moisture. In this sector the waters of the Montes Carpetanos and the Cuerda Larga sub-ranges, concentrated in the river Lozoya and its headwaters, contribute to maintaining water resources in the most unfavourable season. However this situation is replicated in some municipalities of other sector (La Cabrera) (44.12% of the hedgerows are moist), where the irrigated zones are displaced in the search for abundant headwaters. The absolute minimum values (2.23%) coincide with environments containing no abundant headwaters, and which mostly lie upon a granitic rocky piedmont with therophytic pastures.

The semi-moist category are the ones occupying the biggest area (38.64%). They constitute mixed agrosilvosystems with temporary irrigation, associated with the continuity of runoffs from the

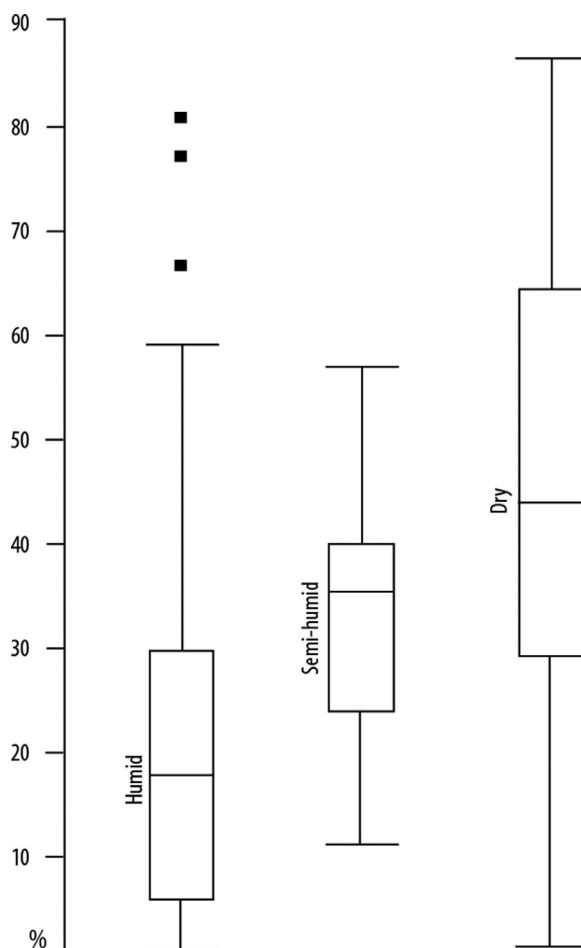


Fig. 8. Area of abandoned hedgerows in relation to the degree of surface soil moisture.

southern slopes of the Central System or with occasional water surpluses from temporary streams and depressions. The highest values (49.08 and 42.61%) are reached in sectors where some medium- and large-sized hedgerows maintain suitable moisture conditions until the start of the summer. The maxima are also high on the granitic piedmont in highly fragmented plots in which the capacity for water retention of small depressions and flat zones plays a vital role. Dry hedgerows occupy 31.48% of the area. Maximum values (1397.50 ha and 748.90 ha) are reached in some parts of Lozoya lacking abundant headwaters or concentrated on dry slopes and in small valleys (Fig. 8).

Regarding the change over time of these rural systems, in 1956 this area was 58,065 ha, whereas in 2014 only 24,400 ha were mapped. These data reflect the generalised abandonment of traditional activities in the rural environment. Nowadays it is possible to distinguish between hedgerows still used up to the present time (42.41%), abandoned ones (48.26%) and urbanised ones (9.33%).

One of the variables influencing the abandonment of the hedgerows is surface soil moisture; 16.65% of the abandoned ones present a high degree of soil moisture, 31.73% pertain to the intermediate category and 51.62% are dry. Falling within the latter category are over half the hedgerows that have been abandoned, and in some sectors they represent over 60%. These figures are repeated in 14 of the 49 municipalities, dry hedgerows being the ones most abandoned in 27 of

Table 1
Area of hedgerows in relation to slope (slope intervals according to Martín Serrano et al., [54]).

	1: <5%	2: 5–10%	3: 10–30%	4: 30–50%	5: 50–70%	6: >70%
	Ha					
Hedgerows 1956	30,839,16	16,139,27	11,852,60	86,81	1,76	0,00
Hedgerows stable in 2017	15,410,25	6349,03	2855,02	9,95	0,03	0,00
Abandoned hedgerows	10,921,42	8566,24	8466,48	68,00	1,01	0,00
	%					
Hedgerows 1956	52,34	27,39	20,12	0,15	0,00	0,00
Hedgerows stable in 2017	62,58	25,78	11,59	0,04	0,00	0,00
Abandoned hedgerows	38,97	30,57	30,21	0,24	0,00	0,00

them. The moist hedgerows, much more fertile and productive and in most cases, more accessible and enduring throughout time, are the least abandoned category (16%). A total of 25% of the municipalities reveal a rate of abandonment of the moist hedgerows of less than 7%, and with the exception of three extreme values, where hardly any other kind of hedgerow exists, the abandonment figures do not exceed 60% in any case.

As we can see in the Table 1, another variable conditioning the stability or abandonment of the hedgerow networks is slope. In 1956, 99.85 % of the hedgerows were situated on slopes of between 0% and 30%. At the present time, they are situated on flat terrain (62.58%) and the ones on slopes greater than 5% (60.78%) are abandoned.

We can conclude that this methodology enables us to typify hedgerow landscape in the continental Mediterranean mountains of the Iberian Peninsula according to the degree of surface soil moisture, and that three types of hedgerows can be established: moist, semi-moist and dry. This classification is innovative, because within the Atlantic environment [55,56], the variable degree of surface soil moisture does not constitute a differentiating element of the landscape. Surface soil moisture was shown to constitute a factor conditioning the type of hedgerow abandoned, over half of which were dry hedges.

The other variable in the maintenance or abandonment of hedgerows is slope. Within the traditional model pertaining to the mid-1900s, the hedgerow landscape was concentrated on flat land or on terrain with moderate slopes. In 1956 the hedgerows delimiting rye fields and dry farming pastures, currently abandoned, were situated on less productive land presenting slopes greater than 10%. This type of hedgerow landscape can also be recognised in other sectors [57–59]. On the contrary, the more gently sloping land (< 10%) currently remains functional and fundamentally comprises meadows with easy access to irrigation. Arable land on steeper slopes is also maintained, although to a lesser degree; this land presents surface soil moisture associated with springs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We would like to acknowledge the financial support of the project funded by Spanish Ministerio de Ciencia e Innovación PID2019-105711RB-C61 /AEI/10.13039/501100011033. Project: “Multifunctional and territorialized agri-food systems in Spain. Conceptuation and governance. Case studies in Madrid and Castilla-La Mancha (SAMUTER MadCIM)

References

[1] I.A. Sánchez, L. Lassaletta, D. McCollin, R.G. Bunce, The effect of hedgerow loss on microclimate in the Mediterranean region: an investigation in central Spain, *Agrofor. Syst.* 78 (1) (2010) 13, doi:10.1007/s10457-009-9224-z.

- [2] I.A. Sánchez, D. McCollin, A comparison of microclimate and environmental modification produced by hedgerows and dehesa in the Mediterranean region: a study in the Guadarrama region, Spain, *Landsc. Urban Plan.* 143 (2015) 230–237, doi:[10.1016/j.landurbplan.2015.07.002](https://doi.org/10.1016/j.landurbplan.2015.07.002).
- [3] Spain MDE from USGS Shuttle Radar Topography. 2004. Available online: https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-shuttle-radar-topography-mission-srtm-1-arc7qt-science_center_objects=0#qt-science_center_objects (accessed on 5 October 2020).
- [4] National Geographic Institute 1:200.000. Archive of Topographic info. Available online: <http://www.ign.es/csw-inspire/srv/eng/main.home>, MTN200 section (accessed on 5 December 2020).
- [5] European Space Agency. Available online: <https://scihub.copernicus.eu/dhus/#/home> (accessed on 10 June 2018).
- [6] A. Lister, T. Lister, T. Weber, Semi-automated sample-based forest degradation monitoring with photointerpretation of high-resolution imagery, *Forests* 10 (10) (2019) 896, doi:[10.3390/f10100896](https://doi.org/10.3390/f10100896).
- [7] G. Cillis A. Lay-Ekuakille V. Telesca D. Statuto, P. Picuno Analysis of the evolution of a rural landscape by combining SAR Geodata with GIS technique, in: Coppola A., Di Renzo G., Altieri G., D'Antonio P. (Eds.), *Innovative Biosystems Engineering for Sustainable Agriculture, Forestry and Food Production. MID-TERM AIIA 2019. Lecture Notes in Civil Engineering*, Springer, Cham, 2020, 67. doi:[10.1007/978-3-030-39299-4_29](https://doi.org/10.1007/978-3-030-39299-4_29)
- [8] A. Carta, T. Taboada, J.V. Müller, Diachronic analysis using aerial photographs across fifty years reveals significant land use and vegetation changes on a Mediterranean island, *Appl. Geogr.* 98 (2018) 78–86, doi:[10.1016/j.apgeog.2018.07.010](https://doi.org/10.1016/j.apgeog.2018.07.010).
- [9] D. Varga, Are agrarian areas in mediterranean mountain regions becoming extinct? A methodological approach to their conservation, *Forests* 11 (2020) 1, doi:[10.3390/f11101116](https://doi.org/10.3390/f11101116).
- [10] P. Ortiz-Báez, P.J. Cabrera-Barona, J. Bogaert, Characterizing landscape patterns in urban-rural interfaces, *J. Urban Manag.* 10 (1) (2021) 46–56, doi:[10.1016/j.jum.2021.01.001](https://doi.org/10.1016/j.jum.2021.01.001).
- [11] F. Baró, E. Gómez-Baggethun, D. Haase, Ecosystem service bundles along the urban-rural gradient: insights for landscape planning and management, *Ecosyst. Serv.* 24 (2017) 147–159, doi:[10.1016/j.ecoser.2017.02.021](https://doi.org/10.1016/j.ecoser.2017.02.021).
- [12] B. Romano, F. Zullo, L. Fiorini, A. Marucci, S. Ciabò, Land transformation of Italy due to half a century of urbanization, *Land Use Policy* 67 (2017) 387–400, doi:[10.1016/j.landusepol.2017.06.006](https://doi.org/10.1016/j.landusepol.2017.06.006).
- [13] L. Salvati, E. De Zuliani, A. Sabbì, L. Cancellieri, M. Tufano, G. Caneva, S. Savo, Land-cover changes and sustainable development in a rural cultural landscape of central Italy: classical trends and counter-intuitive results, *Int. J. Sustain. Dev. World Ecol.* 24 (1) (2017) 27–36, doi:[10.1080/13504509.2016.1193778](https://doi.org/10.1080/13504509.2016.1193778).
- [14] E. Cossart, J. Pic, Y. Le Guen, M. Fressard, Spatial Patterns of vineyard abandonment and related land use transitions in Beaujolais (France): a multiscale approach, *Sustainability* 12 (11) (2020) 4695, doi:[10.3390/su12114695](https://doi.org/10.3390/su12114695).
- [15] G. Modica, S. Praticò, S. Di Fazio, Abandonment of traditional terraced landscape: a change detection approach (a case study in Costa Viola, Calabria, Italy), *Land Degrad. Dev.* 28 (2017) 2608–2622, doi:[10.1002/ldr.2824](https://doi.org/10.1002/ldr.2824).
- [16] S. González-Ávila, C.G.H. López-Leiva, R. Bunce, R. Elena-Rosselló, Changes and drivers in Spanish landscapes at the rural-urban interface between 1956 and 2018, *Sci. Total Environ.* 714 (2020) 136858, doi:[10.1016/j.scitotenv.2020.136858](https://doi.org/10.1016/j.scitotenv.2020.136858).
- [17] J.A. González Díaz, R. Celaya, F. Fernández García, K. Osoro, Rosa, R. García Dynamics of rural landscapes in marginal areas of northern Spain: past, present, and future, *Land Degrad. Dev.* 30 (2019) 141–150, doi:[10.1002/ldr.3201](https://doi.org/10.1002/ldr.3201)
- [18] T. Lasanta, M.P. Errea, E. Nadal-Romero, Traditional agrarian landscape in the Mediterranean mountains, a regional and local factor analysis in the Central Spanish Pyrenees., *Land Degrad. Dev.* 28 (2017) 1626–1640, doi:[10.1002/ldr.2695](https://doi.org/10.1002/ldr.2695).
- [19] Spanish National Geographic Institute (IGN). National Air Orthophotography Programme (PNOA). Available online: <http://www.ign.es/csw-inspire/srv/eng/main.home>, Digital Terrain Model Section (accessed on 20 November 2020).
- [20] Madrid Regional Autonomy Dept. of the Environment (accessed on 30 September 2020).
- [21] Spanish Rustic Cadastre. Available online: <http://ovc.catastro.meh.es/Cartografia/WMS> (accessed on 30 September 2020).
- [22] Madrid Regional Autonomy Dept. of the Environment. Orthophotography section (accessed on 30 December 2020).
- [23] Madrid Regional Autonomy Dept. of the Environment. Land Uses Section (accessed on 10 December 2020).
- [24] Spanish National Geographic Institute (IGN). Archive of historical air photography. Available online: <http://www.ign.es/csw-inspire/srv/eng/main.home>, Historical Orthophotography Section (accessed on 20 October 2020)
- [25] AEMET. Available online: <https://datosclima.es/Aemethistorico> (accessed on 5 June 2020).
- [26] M. El Hajj, N. Baghdadi, M. Zribi, H. Bazzi, Synergic use of sentinel-1 and sentinel-2 images for operational soil moisture mapping at high spatial resolution over agricultural areas, *Remote Sens.* 9 (12) (2017) 1292, doi:[10.3390/rs9121292](https://doi.org/10.3390/rs9121292).
- [27] J. Dari, P. Quintana-Seguí, M.J. Escorihuela, V. Stefan, L. Brocca, R. Morbidelli, Detecting and mapping irrigated areas in a Mediterranean environment by using remote sensing soil moisture and a land surface model, *J. Hydrol.* 596 (2021) 126129, doi:[10.1016/j.jhydrol.2021.126129](https://doi.org/10.1016/j.jhydrol.2021.126129).
- [28] H. West, N. Quinn, M. Horswell, P. White, Assessing vegetation response to soil moisture fluctuation under extreme drought using sentinel-2, *Water* 10 (7) (2018) 838, doi:[10.3390/w10070838](https://doi.org/10.3390/w10070838).
- [29] R. Corona, L. Foïs, N. Montaldo, The role of vegetation growth on the estimate of soil moisture in a grass field using sentinel-1 and sentinel-2 observations and data assimilation, *EGU Gen. Assembl.* (2021) 2021 online, 19–30 Apr 2021, EGU21-15679, doi:[10.5194/egusphere-egu21-15679](https://doi.org/10.5194/egusphere-egu21-15679).
- [30] P. Nasta, et al., Integrating ground-based and remote sensing-based monitoring of near-surface soil moisture in a Mediterranean environment, in: *Proceedings of the IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor)*, Portici, Italy, 2019, pp. 274–279, doi:[10.1109/MetroAgriFor.2019.8909226](https://doi.org/10.1109/MetroAgriFor.2019.8909226).
- [31] M. Ambrosone, A. Matese, S.F. Di Gennaro, B. Gioli, M. Tudoroiu, L. Genesio, F. Miglietta, S. Baronti, A. Maienza, F. Ungaro, P. Toscano, Retrieving soil moisture in rainfed and irrigated fields using sentinel-2 observations and a modified OPTRAM approach, *Int. J. Appl. Earth Obs. Geoinf.* 89 (2020) 102113, doi:[10.1016/j.jag.2020.102113](https://doi.org/10.1016/j.jag.2020.102113).
- [32] K. Dabrowska-Zielinska, J. Musiał, A. Malinska, M. Budzynska, R. Gurdak, W. Kiryla, M. Bartold, P. Grzybowski, Soil moisture in the Biebrza Wetlands retrieved from sentinel-1 imagery, *Remote Sens.* 10 (2018) 121979, doi:[10.3390/rs10121979](https://doi.org/10.3390/rs10121979).
- [33] H.O. Benbrahim, A. Merzouki, K. Minaoui, Quantification of soil moisture variability over agriculture fields using sentinel imagery, in: *Proceeding of the 2020 International Conference on Intelligent Systems and Computer Vision (ISCV)*, Fez, Morocco, 2020, pp. 1–4, doi:[10.1109/ISCV49265.2020.9204120](https://doi.org/10.1109/ISCV49265.2020.9204120).
- [34] J. Serrano, S. Shahidian, S. Marques da, José, "Monitoring seasonal pasture quality degradation in the Mediterranean Montado ecosystem: proximal versus remote sensing", *Water* 10 (10) (2018) 1422, doi:[10.3390/w10101422](https://doi.org/10.3390/w10101422).

- [35] J. Serrano, S. Shahidian, J. Marques da Silva, Evaluation of normalized difference water index as a tool for monitoring pasture seasonal and inter-annual variability in a mediterranean Agro-silvo-pastoral system, *Water* 11 (2019) 62, doi:[10.3390/w11010062](https://doi.org/10.3390/w11010062).
- [36] A. Anand ,P. Singh P.K. Srivastava, M. Gupta, Chapter 19 - GIS-based analysis for soil moisture estimation via Kriging with external drift, in: K. P. Srivastava, M. Gupta, G. Tsakiris, N. W. Quinn (Eds.), *Agricultural Water Management*, Academic Press, 2021, pp. 391–408. 10.1016/B978-0-12-812362-1.00019-9.
- [37] M.J. El Hamidi, A. Larabi, M. Faouzi, et al., Spatial distribution of regionalized variables on reservoirs and groundwater resources based on geostatistical analysis using GIS: case of Rmel-Oulad Ogbane aquifers (Larache, NW Morocco), *Arab. J. Geosci.* 11 (104) (2018) 104–110, doi:[10.1007/s12517-018-3430-9](https://doi.org/10.1007/s12517-018-3430-9).
- [38] P.K. Srivastava, P.C. Pandey, G.P. Petropoulos, N.N. Kourgialas, V. Pandey, U. Singh, GIS and Remote sensing aided information for soil moisture estimation: a comparative study of interpolation techniques, *Resources* 8 (2) (2019) 70, doi:[10.3390/resources8020070](https://doi.org/10.3390/resources8020070).
- [39] T.E. Ochsner, E. Linde, M. Haffner, J. Dong, Mesoscale soil moisture patterns revealed using a sparse in situ network and regression Kriging, *Water Resour. Res.* 55 (2019) 4785–4800, doi:[10.1029/2018WR024535](https://doi.org/10.1029/2018WR024535).
- [40] H. Chen, L. Fan, W. Wu, et al., Comparison of spatial interpolation methods for soil moisture and its application for monitoring drought, *Environ. Monit. Assess.* 189 (2017) 525, doi:[10.1007/s10661-017-6244-4](https://doi.org/10.1007/s10661-017-6244-4).
- [41] T. Tunçay, Comparison quality of interpolation methods to estimate spatial distribution of soil moisture content, *Commun. Soil Sci. Plant Anal.* 52 (4) (2020) 353–374, doi:[10.1080/00103624.2020.1854283](https://doi.org/10.1080/00103624.2020.1854283).
- [42] M.L. Fonteh, F. Theophile, M.L. Cornelius, R. Main, A. Ramoelo, M.A. Cho, Assessing the utility of sentinel-1 c band synthetic aperture radar imagery for land use land cover classification in a tropical coastal systems when compared with landsat 8, *Jour. of Geogr. Inf. Syst.* 8 (04) (2016) 495.
- [43] J. Deutscher, K. Gutjahr, R. Perko, H. Raggam, M. Hirschmugl, M. Schardt, Humid tropical forest monitoring with multi-temporal L-, C-and X-band SAR data, *Anal. Multitemporal Remote Sens. Images (MultiTemp)* (2017) 1–4 9th International Workshop on the IEEE.
- [44] I.N. Garkusha, V.V. Hnatushenko, V.V. Vasyliov, Research of influence of atmosphere and humidity on the data of radar imaging by sentinel-1, in: *Proceedings of the IEEE 37th International Conference on Electronics and Nanotechnology (ELNANO)*, 2017, pp. 405–408.
- [45] M. Sadeghi, E. Babaeian, M. Tuller, S.B. Jones, The optical trapezoid model: a novel approach to remote sensing of soil moisture applied to sentinel-2 and landsat-8 observations, *Remote Sens. Environ.* 198 (2017) 52–68.
- [46] A. Kerckhof, V. Spalevic, V. Van Eetvelde, J. Nyssen, Factors of land abandonment in mountainous Mediterranean areas: the case of Montenegro settlements, *SpringerPlus* 5 (2016) 485, doi:[10.1186/s40064-016-2079-7](https://doi.org/10.1186/s40064-016-2079-7).
- [47] J. Lieskovský, P. Bezák, J. Špulerová, T. Lieskovský, P. Koleda, M. Dobrovodská, U. Gimmi, The abandonment of traditional agricultural landscape in Slovakia—Analysis of extent and driving forces, *J. Rural Stud.* 37 (2015) 75–84.
- [48] J.M. Terres, L.N. Scacchiafichi, A. Wania, M. Ambar, E. Anguiano, A. Buckwell, D. Strijker, Farmland abandonment in Europe: identification of drivers and indicators, and development of a composite indicator of risk, *Land Use Policy* 49 (2015) 20–34.
- [49] A. Li, W. Deng, W. Zhao, *Land Cover Change and Its Eco-environmental Responses in Nepal*, Springer Nature Singapore, 2017, doi:[10.1007/978-981-10-2890-8](https://doi.org/10.1007/978-981-10-2890-8).
- [50] J. Rodrigo Comino, S.D. Keesstra, Cerdà, Connectivity assessment in Mediterranean vineyards using improved stock unearthing method, LiDAR and soil erosion field surveys, *Earth Surf. Process. Landf.* 43 (2018) 2193–2206, doi:[10.1002/esp.4385](https://doi.org/10.1002/esp.4385).
- [51] M. Ortuño, M. Guinau, M. Calvet, J. Furdada, G. Bordonau, J. Ruiz, A. Camafort, Potential of airborne LiDAR data analysis to detect subtle landforms of slope failure: Portainé, central pyrenees, *Geomorphology* 295 (2017) 364–382, doi:[10.1016/j.geomorph.2017.07.015](https://doi.org/10.1016/j.geomorph.2017.07.015).
- [52] R.R. Aryal, H. Latifi, M. Heurich, et al., Impact of slope, aspect, and habitat-type on LiDAR-derived digital terrain models in a near natural, heterogeneous temperate forest., *PFG* 85 (2017) 243–255, doi:[10.1007/s41064-017-0023-2](https://doi.org/10.1007/s41064-017-0023-2).
- [53] A.S.Z. Chase, D.Z. Chase Chase, LiDAR for archaeological research and the study of historical landscapes, in: Masini N., Soldovieri F. (Eds.), *Sensing the Past. Geotechnologies and the Environment*, Springer, Cham, 2017, vol 16. doi:[10.1007/978-3-319-50518-3_4](https://doi.org/10.1007/978-3-319-50518-3_4).
- [54] M. Serrano, A. Salazar, F. Nozal, F. Suárez, A. Mapa, *Guía Para su Elaboración Geomorfológico de España*, Instituto Geológico y Minero de España, 2004.
- [55] P. Brunet, *L'Atlas des Paysages Ruraux de France* (Ed.), Jean Pierre De Monza, 1992.
- [56] F.H. Aalen, K. Whelan, M. Stout, *Atlas of the Irish Rural Landscape*, University of Toronto Press, 1997.
- [57] T. Kizos, M. Koulouri, Agricultural landscape dynamics in the Mediterranean: Lesvos (Greece) case study using evidence from the last three centuries, *Environ. Sci. Policy* 9 (4) (2006) 330–342.
- [58] I.A. Sánchez, D. McCollin, A comparison of microclimate and environmental modification produced by hedgerows and dehesa in the Mediterranean region: a study in the Guadarrama region, Spain., *Landsc. Urban Plan.* 143 (2015) 230–237.
- [59] I.A. Sánchez, L. Lassaletta, D. McCollin, R.G. Bunce, The effect of hedgerow loss on microclimate in the Mediterranean region: an investigation in Central Spain, *Agrofor. syst.* 78 (1) (2010) 13.