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LAND USE CHANGES AND EFFECTS OF RAINFALL ON VEGETATION COVER IN TWO MEDITERRANEAN BASINS (MÁLAGA, SPAIN)

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ABSTRACT. The western Mediterranean is an area particularly affected by the effects of climate change, which makes it a hotspot, and it is also an area where there is particular competition for land use, where subtropical crops coexist with traditional crops including vines, olives, and almond trees, and where there is growing demand for urban development and tourism. It is one of the most sensitive to the effects of climate change because of the markedly contrasting extreme events, including heat waves, torrential rains and drought. In this study we analysed changes in land use, torrential events and the effect of rainfall on vegetation cover and soils in two basins, the main objective being to analyse the evolution of land use and water erosion in recent decades. The two basins are similar but have different configurations and contrasting uses. One has steep slopes and is characterized by more typical Mediterranean crops, such as vineyards, while the other has been subject to clearing that has modified the steep slopes, and where there has been a change to more competitive crops, including subtropical crops. The results highlight the continuous increase of irrigated crops and urban areas and a gradual disappearance of rainfed crops, the occurrence between torrential events and the correlation between monthly rainfalls and vegetation cover.

Keywords: Mediterranean basins; land use; rainfalls; vegetation cover.

INTRODUCTION

In recent years, a large number of environmental issues have emerged both

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globally and regionally, including risks of soil erosion and changes in the water cycle (Douville *et al.*, 2021). The increased risks associated with heavy rainfall events are not only environmental issues, but increase the vulnerability of affected communities, including anthropogenic factors have also become apparent with the expansion of land clearing and changes in land use in various areas (IPCC, 2001, 2007, 2014, 2019). These changes affect economic activities, including agriculture (Hennessy and Pittock, 1995; Ferrari *et al.*, 2013; Martínez Navarro, 2018, Sencialez-Gonzáles and Ruiz-Sinoga, 2021).

Increases in the frequency and intensity of extreme events, especially extreme weather hazard, heat waves, drought, torrential rainfall; referred to as SWEATS throughout the Spanish Mediterranean are key to the study of sensitivity and fragility because of their continuous pressure on this region (Viceto *et al.*, 2017; Doblas-Reyes *et al.*, 2021). This is because ongoing soil impoverishment is likely to occur in this region as a result of increased torrential events, dry spells, high temperatures, erosion, and changes to the water cycle, together with the direct impacts likely on these soil degradation processes under climate change (Seneviratne *et al.*, 2021; Sillero-Medina *et al.*, 2021). Anthropogenic activities and their impacts in this region have already caused progressive environmental degradation (Sinoga and Martínez-Murillo, 2012), and are of great concern because of their effects on many socio-economic activities (agriculture, energy production, drinking water supply) and roles in the occurrence of natural risks including droughts, and floods (Ferrari *et al.*, 2013). This is particularly evident in Mediterranean agriculture, because of the marked contrasts among basins, having different uses, some maintaining traditional Mediterranean agriculture and others involved in highly competitive agriculture.

In this study we analysed changes in land uses over the last 30 years and the possible effects of rainfall on vegetation cover and soil in two Mediterranean river basins, both located in the province of Malaga, Spain (*Figure 1*).

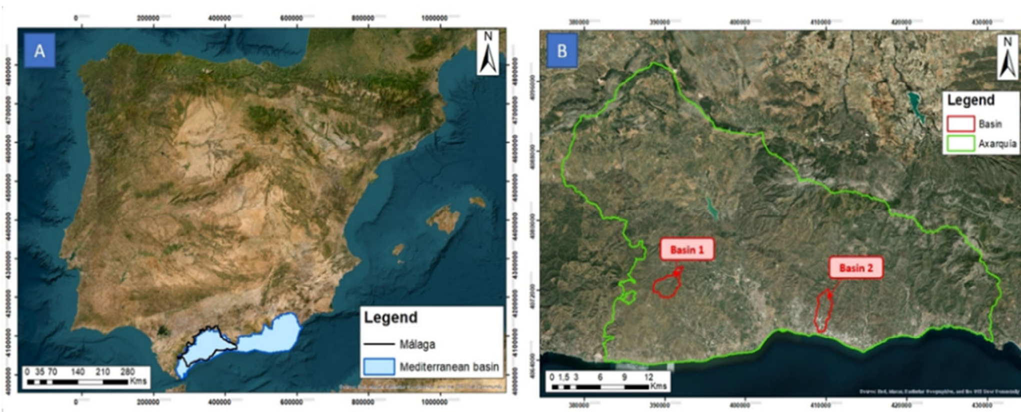

Figure 1 – Location of the study basins

These basins are located in a complex study area characterized by steep slopes, proximity to the sea, the presence of very erodible lithology, specific climatic characteristics, and proximity to the tourist areas of the Costa del Sol.

Two main objectives were set to enhance understanding of the evolution of the Mediterranean-river basins in the study:

1. To detect, analyse and compare changes in land use over the last 30 years in the two basins. The updating of land use was carried out according to "Mapa de Usos y Coberturas Vegetales del Suelo de Andalucía" (MUCVA) methodology. This update allowed analyse the evolution of current land use with the land uses of the last 30 years.

2. To detect torrential rainfall events and analyse the evolution of vegetation covers as a function of rainfall in the study basins. Torrential rainfall events and their possible effect on soil were investigated for the period 1993–2021, grouping the most prominent torrential events. Meanwhile, the relationship of monthly and annual rainfall to the vegetation cover, expressed as NDVI (Normalized Difference Vegetation Index), has been analysed over the last five years (2017–2022).

Finally, these two main objectives allowed to analyse the difference in land use between the two basins and how they have been affected by rainfall and the development of vegetation cover in each basin. The results obtained will demonstrate the need for and importance of knowing the changes in land use in Mediterranean basins in the last three decades especially those in which the loss of vegetation cover makes them more susceptible to erosion processes. The vegetation cover can be reduced not only by human action but the changes in the general rainfall regime towards a drier one. Thus, the detection of torrential rainfall events and the correlation analysis between NDVI and the monthly rainfalls allow to establish the evolution of vegetation cover related to general rainfall behaviour. It goes deeper into the climatic dynamics of the Mediterranean basins as an indicator of climatic crisis in agriculture and its link with the territory. There are extensive studies focused on large-scale vegetation-climate interactions using remote sensing and meteorological variables (Hicke *et al.*, 2002; Baldi *et al.*, 2008; De Jong *et al.*, 2013, etc.) and this information will contribute to the establishment of adaptation and mitigation scenarios in the future with the aim of implementing good practice dissemination plans, within the framework of climate crisis adaptation/mitigation strategies.

MATERIALS AND METHODS

The study area

The two Mediterranean basins (Cuenca de Almáchar: Basin 1; and Cuenca de Sayalonga: Basin 2) are located in the Axarquia region, in the east of Malaga province, in the southern catchment area of Spain. The two basins are very similar, and their general characteristics largely coincide in terms of the physical and climatic environment, although with slight differences. Thus, the first basin with steep slopes and the emergence of more sensitive crops, such as vineyards, will increase its fragility after torrential events, while the other basin will be differentiated with the appearance of clearings that decrease the steep slopes together with changes to more competitive crops, such as subtropical crops.

The climatic unit where they are located is Subtropical Mediterranean with an average temperature of 17.2º and 17.3º, coinciding with a land use mainly based on agriculture, with irrigated woody crops being the most widespread, more specifically subtropical, and to a lesser extent, but more popular, the olive grove (*Figure 1*).

Both basins have a similar extension area (671.77 ha and 651.99 ha), with an average altitude of 374.72 meters above sea level (masl) in Basin 1 and 245.66 masl in Basin 2. On the other hand, the slope of both basins is remarkable, since Basin 1 has a higher average slope than Basin 2 (47.58% B1 and 40.6% B2) (*Figure 2*).

The basins are located within the Alpujárrides Complex in the inner zones of the Betic Cordilleras, specifically in the Benamocarra and Sayalonga units (upper mantos; Geological Map of Andalusia, Junta de Andalucía 1985).

The Alpujarride materials contain three large lithological units: Paleozoic dark micaschists, Paleozoic grey schists and quartzschists and Triassic marbles, which appear in the region in several units of different degrees of metamorphism, superimposed by low-angle normal faults and fault lines. The Maláguide materials, with a much lower degree of metamorphism, correspond to Paleozoic phyllites, metarenisks, limestones and grauwacs, and Triassic marls and gypsiferous sandstones, however, in this case, only in the immediate vicinity.

The soils are mainly Eutric Cambisols and Regosols, generally on the metapelitic materials of the Alpujarrides and Maláguides units; or Lithosols on the carbonate materials (FAO, 2022), both Alpujarrides units and of the Dorsal and Internal Subbetic. There are also Calcic Cambisols in transition zones between both sets of lithologies, Vertic Cambisols on the sedimentary materials of the flysch and the postorogenic basins, or Luvisols on the Quaternary (alluvial) coatings.

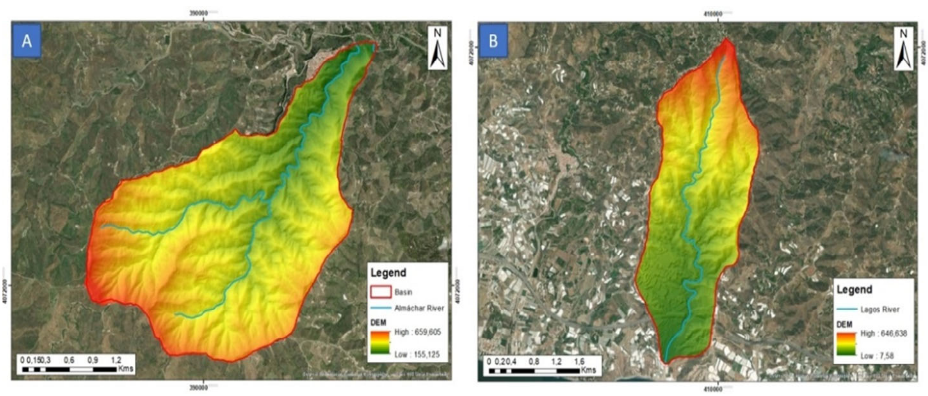

Figure 2 – DEM and hydrographic network of Basin 1 (A) and Basin 2 (B)

The Cambisols are productive soils rich in nutrients or bases (Ca, Mg, K and Na). Because of the steep slopes, large amounts of sediment are transported and deposited on the valley floor after torrential rainfall events, and marked water erosion occurs on the steeper slopes.

Methodologies

The study was based on a broad, interdisciplinary and transversal approach based on geomatics technique including the use of GIS (Geographic Information Systems), analysis and interpretation of satellite images (Sentinel 2 and SPOT 6/7), management of climatic databases involving high temporal resolution rainfall data from meteorological stations (Data obtained through the SAIH Hidrosur Network, Station 43 and Station 44), and characterization of the territory (land use and vegetation cover).

The current land uses in two Mediterranean basins were analysed at the plot scale, enabling characterization of the territory according to its functional dimensions or current socio-economic used (National Geographic Institute, 2022). The most significant changes in recent decades were also investigated, together with an analysis of local processes in the basins over the last five years, including, rainfall, and vegetation cover, using the Normalized Difference Vegetation Index (NDVI). Particular attention was paid to torrential events including heavy rainfall characterized by high intensity in each period, which have the capacity to have major impacts and to produce significant changes in each area (Martín and Llasat, 2000). In this respect, rainfall events equal to or greater than 100 mm in 24 h, 60 mm in 1 h, and 10 mm in 10 min were considered torrential (Martín Vide, 1989; AEMET, 2013; Sillero Medina *et al*., 2019). These objectives will be discussed in more detail in the following sections.

Land use changes

The changes in land use, analysed using ArcGIS software (University of Malaga license), were adapted and cropped according to “Mapa de Usos y Coberturas Vegetales del Suelo de Andalucía” (MUCVA) methodology on the Mediterranean basins for 1977, 1984, 1999, 2003 and 2007. These data were downloaded from the Environmental Information Network (REDIAM). According to the Department of Sustainability, Environment and Blue Economy of the Regional Government of Andalusia, the regional MUCVA Project is a map of land use and land cover in Andalusia; it was created in 1991 by adapting of the Corine Land Cover methodology to the physical and territorial conditions of Andalusia. To assess the current land uses, a suitable classification was sought that was compatible with previous classifications.

For this purpose, the MUCVA classification was adapted to analyse agriculture in the basins, based on the following twelve classes:

1. Heterogeneous agricultural areas.
2. Open areas with sparse vegetation.
3. Dense woodland formations.
4. Grassland formations, scrubs, shrubs and herbaceous plants with or without trees.
5. Built and altered surfaces.

6. Irrigated areas.
7. Irrigated areas: subtropical.
8. Irrigated areas: greenhouses and crops grown under plastic.
9. Rainfed areas.
10. Rainfed areas: olive groves.
11. Rainfed areas: vineyard.
12. Wet areas and water surfaces.

The classes were defined based on SPOT 6/7 images (May and June, 2021) at 1.5 m spatial resolution (Airbus). Subsequently, two supervised classifications were developed based on parallelepipeds, following the non-parametric rule using Erdas Image 2022 software. Following removal of numerous initial errors in some categories because of their similar spectral responses, the land uses were digitized at the plot scale, using the agricultural plots as reference (SIGPAC, 2022) and topical aerial orthophotographs of the PNOA (Plan Nacional de Ortofotografia Aérea de máxima actualidad, available at the CNIG-IGN download service). Subsequently, categories were reclassified and errors were corrected.

Reliability assessment was done using a confusion matrix with 50 sampling points in each catchment; this was applied to all categories and Kappa statistical analyses were obtained.

Detection of torrential rainfall events

Ten-minute rainfall data (1993–2021) were obtained from two pluviometric stations close to the study basins and filtered. The stations were Station 43, on the Benamargosa river, (near Basin 1), and Station 44 on the Torrox river, (near Basin 2) according to the Department of Agriculture, Fisheries, Water and Rural Development, Dirección Directorate General of Water Infrastructures, the Regional Government of Andalusia. The data were obtained through the SAIH Hidrosur Network (2023).

Torrential events have been considered as the grouping of torrential precipitation at daily (≥100 mm in 24 h) (Santos Deltell, 1991; Olcina Cantos, 2000; Senciales and Ruiz, 2013) and hourly (≥60 mm h-1) scales (AEMET, 2013), and the events recorded in each of the environments that reach these thresholds have been quantified, which has allowed us to analyze their reiteration and differentiated incidence in each of the study areas.

In addition, according to the cataloging offered by the State Meteorological Agency (AEMET), there is a definition of a new torrential threshold at a ten-minute scale (≥10 mm in 10 min). To summarize, precipitation at daily (≥100 mm in 24 h), hourly (≥60 mm in 1 h) and ten-minute (≥10 mm in 10 min) scales were considered.

Data obtained from the SAIH Hidrosur network (Stations 43 and 44) were used to determine, the 10-min rainfall from 1993 to 2021.

Additional information on the stations is included in *Table 1*.

Table 1 – Stations used as references

Nº	Station	Province	Station Type	X	Y	Z	Basin
43	Río de Benamargosa	Málaga	Gauging	392622	4078582	146	1
44	Torrox	Málaga	Meteorological	416887	4067779	340	2

Evolutionary analysis of NDVI as a function of rainfall

The mean NDVI value for each study catchment for all months for the period 2017–2022 was obtained for the analysis. To avoid variations in the values, a cloud mask was applied to eliminate the effect of clouds.

This procedure involved use of in the free SNAP software, using Sentinel 2 images with 2A pre-processing (120 images, 1 per month for 5 years and two UTM grids, SUF for Basin 1 and SVF for Basin 2). The free images were downloaded from the Copernicus service (Copernicus Open Access Hub, 2023). The index was calculated using the following *Eq. (1)* (Rouse *et al.*, 1974; Bannari *et al.*, 1995):

$$NDVI = (NIR - R)/(\mathrm{NIR} + \mathrm{R}) \qquad (1)$$

where NIR is the near-infrared reflectance corresponding to Band 8, and R is the red reflectance corresponding to Band 4.

For precipitation values, monthly values were plotted for the last five years and completed up to 2022 (2017–2022) using data from AEMET.

NDVI has been used in this work as an expression of the vegetation cover which has been analysed and established in different studies (Jiang *et al.*, 2006; Gao *et al.*, 2020; Tenreiro *et al.*, 2021), by means of linear, quadratic, or complex relationships.

Based on the NDVI and precipitation monthly series, a year-to-year correlation analysis were carried out. Relationships between NDVI and rainfalls have been analysed in different parts of the world and climates, showing good spatial and temporal correlations especially in dry areas as the studied in this work (Davenport and Nicholson, 1993; Fabricante *et al.*, 2009; Georganos et al., 2017; Garai *et al.*, 2022). In this work, correlations were tested using the moving averages for both variables calculated (i) from the previous month, the month under consideration, and the month after, and (ii) the two previous months, the month under consideration, and the two following months.

RESULTS AND DISCUSSION

Detection and analysis of changes in land use over the last 30 years

The following figures (*Figure 3* and *Figure 4*) show the current land use in the two study catchments in 2021-2022. The data are based on plot scale, updating the MUCVA and SIGPAC as a reference.

The above figures show the contrast between the two Mediterranean basins. In both basins there is a notable predominance of heterogeneous agricultural areas, the so-called Mediterranean trilogy, which are a mixture of small plots, abandoned fields and shrub and herbaceous cultivated plots. From the agricultural point of view, in Basin 1 (*Figure 3*) there is a predominance of rainfed crops, such as olive groves and vineyards, while in Basin 2 (*Figure 4*) there is a north-south contrast, with traditional rainfed crops in the northern part and irrigated crops in the south (greenhouses and subtropical crops).

Table 2 and *Table 3* show the evolution and changes in land use over the three decades from 1977 to 2021–2022. In the period 1977–2007 the data are based on a scale of 1:25000, whereas for 2021/2022 the data are based on the plot scale.

Table 2 and *Table 3* highlight evolution of the land use of each basin over the last three decades. The adaptation of the MUCVA classification has developed more towards agriculture as the aim was to understand the relationship between their spatial extent and evolution in the same region. It is relevant to clarify that the values from 1977 to 2007 were the original MUCVA values uploaded to REDIAM, while the 2021/2 values were obtained from the adaptation of that methodology. Therefore, in the last period, when a greater interval of years will be observed between 2007 and 2021/2, changes.

In Basin 1 (*Table 2*) rainfed crops predominated, covering 40.82% of the basin. Among these, vineyards comprised 28.04% and olive groves 12.78%. Their heterogeneity is notable, as rainfed and irrigated crops are distributed throughout the basin. The temporal evolutions show few changes, although there has been a recent decrease in heterogeneous agricultural areas and grassland-scrubland formations in favour of more defined crops including vineyards, olive groves, and subtropical crops. This may be more related to the higher resolution of the original data (images) than to real changes that have allowed us a more detailed classification of agricultural areas although a small increase in built-up areas was observed.

In Basin 2 (*Table 3*) irrigated crops predominated, comprising 34.72% of the surface area. Among the irrigated crops, 25.68% are subtropical and 8.43% are greenhouse and crops under plastic.

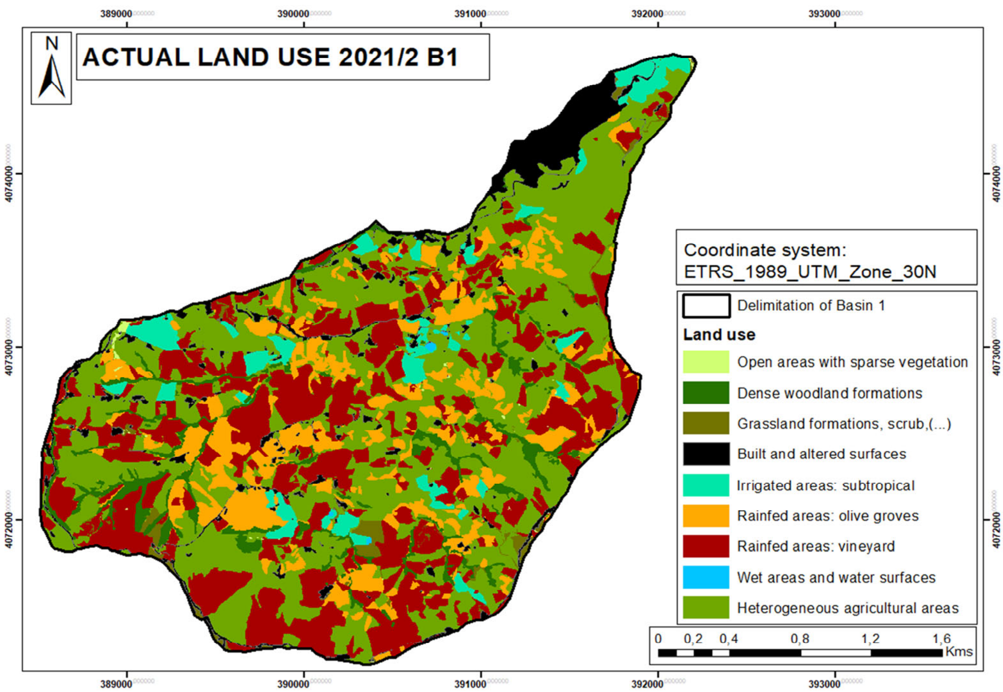

Figure 3 – Actual land uses in Basin 1

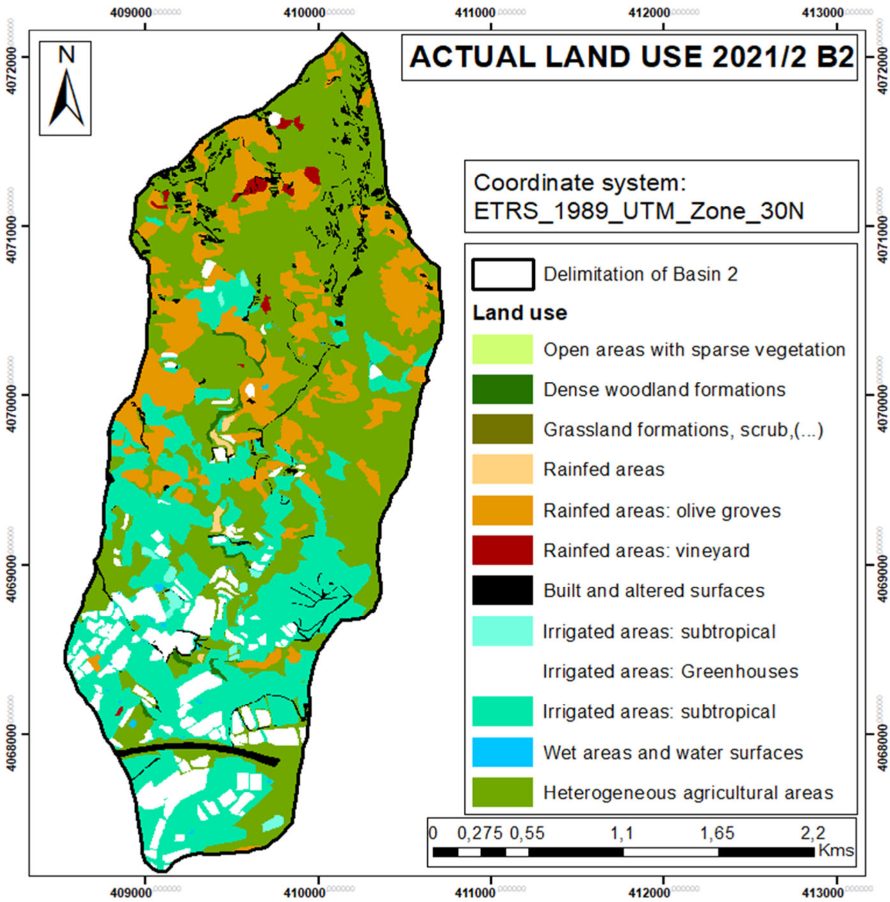

Figure 4 – Actual land uses in Basin 2

However, the distribution was not uniform, as indicated above, as irrigated crops are concentrated in the south of the basin, while rainfed crops are concentrated in the north. The evolution in this basin also shows relative stability until recently, when there has been a decrease in the heterogeneous agricultural areas and pasture land, and an increase in rainfed (olive groves) and irrigated (subtropical and greenhouses) crops. It should be noted that the irrigated areas in 1977 and 1984, greenhouses and subtropical areas, due to their smaller size and the limitations of the data sources of those years were not captured and remained with values of 0%, which supposes that there is a small error that cannot be calculated.

In conclusion, both basins have had a predominance of traditional agricultural land uses, mainly rainfed such as olive crops, vineyards, cereal and pasture or areas with shrub, identified more clearly in the last survey of higher detail and resolution, with few changes in general.

Table 2 – Evolution of the area (%) of land uses in Basin 1 from 1977 to 2021/22

B1 %	1977	1984	1999	2003	2007	2021/2
Heterogeneous agricultural areas	58.35	58.35	57.97	57.97	57.33	**41.37**
Open areas with sparse vegetation	0.38	0.38	0.38	0.38	0.38	**0.18**
Dense woodland formations	0.55	0.55	0.55	0.55	0.55	**4.74**
Grassland formations, scrub, (*)	17.35	17.35	17.35	17.35	17.35	**1.66**
Built and altered surfaces	1.38	1.78	1.78	1.78	2.41	**6.31**
Irrigated areas: subtropical	0.62	0.62	1.00	1.00	1.00	**4.84**
Rainfed areas	18.72	18.32	18.32	18.32	18.32	**0.00**
Rainfed areas: olive groves	2.15	2.15	2.15	2.15	2.15	**12.78**
Rainfed areas: vineyard	0.51	0.51	0.51	0.51	0.51	**28.04**
Wet areas and water surfaces	0.00	0.00	0.00	0.00	0.00	**0.08**

*Grassland formations, scrubs, shrubs and herbaceous plants with or without trees

Table 3 – Evolution of the area (%) land uses in Basin 2 from 1977 to 2021/2022

B2 %	1977	1984	1999	2003	2007	2021/2
Heterogeneous agricultural areas	85.25	86.91	70.93	72.30	70.49	**45.05**
Open areas with sparse vegetation	0.00	0.15	2.07	0.29	0.46	**0.00**
Grassland formations, scrub, (*)	9.33	8.76	8.39	7.83	7.29	**0.00**
Dense woodland formations	0.00	0.00	0.00	0.00	0.00	**0.54**
Rainfed areas	3.18	1.47	0.24	0.13	0.08	**0.29**
Rainfed areas: olive groves	1.61	1.55	1.55	1.55	1.55	**14.93**
Rainfed areas: vineyard	0.00	0.00	0.00	0.00	0.00	**0.60**
Built and altered surfaces	0.02	0.02	5.66	5.49	7.57	**3.65**
Irrigated areas	0.61	1.15	2.28	0.95	1.12	**0.61**
Irrigated areas: greenhouses	0.00	0.00	7.41	8.98	8.96	**8.43**
Irrigated areas: subtropical	0.00	0.00	1.40	2.30	2.30	**25.68**
Wet areas and water surfaces	0.00	0.00	0.06	0.18	0.18	**0.22**

*Grassland formations, scrubs, shrubs and herbaceous plants with or without trees

However, from the final years of 20th and the 21th century an increase of the irrigated areas (both greenhouses and subtropical crops), together the urban areas have been occurred, due to a higher human activity, especially in the south part of basin 2. The increase of irrigated areas does not produce to a loss of vegetation cover, on the contrary, but it can be a problem in an area with scarce precipitations, that lead to an abandonment of the crops, temporary or definitive.

Detection of torrential events

The 10-min precipitation for each station was filtered and all precipitation were grouped in categories. *Table 4* and *Table 5* show rainfalls exceeding 10 mm in 10 min in a day.

- There were no days on which rainfalls exceeded a total of 60 mm in one hour.
- *Table 6* and *Table 7* show data on precipitation exceeding 100 mm in 24 hours, including the day of occurrence.

Table 4 – Station 43

Year	Month	Day	Rainfall
1994	11	4	10.4
1997	9	27	10
1999	11	11	11.4
1999	11	11	10.1
2003	11	22	10.9
2006	9	12	11.8
2009	2	1	13
2010	1	7	10.6
2010	12	7	11.5
2012	9	28	13.2
2012	11	17	10.5
2012	11	17	27.2
2015	9	30	20.7
2015	9	30	15.4
2017	11	3	10.3
2021	5	23	12.7

Table 5 – Station 44

Year	Month	Day	Rainfall
2002	3	3	11.6
2002	11	14	12.5
2007	9	21	11.4
2007	9	21	12.1
2007	9	21	12.9
2007	9	21	12.9
2007	9	21	10.1
2008	10	9	10.1
2008	11	19	10
2010	12	22	10.8
2012	9	28	20.9
2012	9	28	10.1
2014	1	18	13.2
2015	9	30	10
2015	9	30	11
2015	10	20	10
2016	1	30	13.4
2016	1	30	12
2020	11	5	10.7

Table 6 – Station 43

Year	Month	Day	Rainfall
2008	10	31	106.8
2009	2	1	113
2012	11	17	129.4

Table 7 – Station 44

Year	Month	Day	Rainfall
2007	9	21	124.4

The data show that the most torrential events were associated with rainfall greater than 10 mm in 10 min, with a total of 35 torrential events (16 at Station 43 and 19 at Station 44) occurring between 1993 and 2021; these represent aggressive processes that will have negatively affected the soil. The occurrences were concentrated in autumn and winter, especially October to February. The years 2007/08 and 2015/16 were not particularly rainy years (365–348 mm and 316–341 mm, respectively), in both cases having lower rainfall than the average annual rainfall (385–299 mm) for the last 30 years. The wettest years were 2009/10 (811–533 mm) and 2012/13 (639–450 mm). No torrential events involving rainfall > 60 mm in 1 hour were observed, but four events >100 mm in 24 hours occurred, three recorded at Station 43 (in 2008/2009 and 2012/2013) and one recorded at Station 44 (2007/2008).

These recurring torrential events have high erosive capacity that degrades the geomorphological system (López and Romero, 1993; Ruiz Sinoga *et al.*, 2010) and the productive capacity of the soil (Encina and Ibarra, 2003; Hueso González *et al.*, 2018). These events occur throughout the year, although in this case study they were concentrated mainly in autumn and winter, especially in the stations closest to the coast (Rodrigo, 2010; Acero *et al.*, 2011) where the Mediterraneity factor intervenes (I Clar, 1988; De Castro *et al.*, 2005; Ruiz Sinoga *et al.*, 2015).

Evolution of NDVI in relation to rainfall

An analysis of vegetation land cover was carried out using the NDVI for the period 2017–2022 enabling comparison with rainfall and to assess the impact of overall rainfall and more prominent events.

Monthly and annual evolution of the NDVI in the period 2017–2022

Table 8 and *Table 9* show the evolution of NDVI from January to December in the period 2017–2022 the annual mean for each season.

Basin 1 had a higher mean annual NDVI (0.416) than Basin 2 (0.372). This is consistent with the observed differences and the longitudinal rainfall gradient in this sector of the Mediterranean coast (Ruiz Sinoga *et al.*, 2015). January, February, March and December had the highest monthly NDVI values, with January having the highest mean NDVI in each year; the exception in December 2018/2019, which had the highest NDVI in both basins (0.567 and 0.523, respectively). The lowest average monthly NDVI occurred in the summer months (June–September), with August 2022 having the lowest value in each basin (0.294 and 0.240, respectively) during the period of the study.

In Basin 1 the year 2020/2021 had the highest mean annual NDVI, while in Basin 2 this occurred in 2019/2020. In all years, except 2021/2022, the values were similar for the two basins (0.43–0.44 and 0.37–0.39, respectively). The lowest values occurred in both basins in 2021/2022 (0.35–0.34).

In both basins the NDVI was relatively low at the beginning of the hydrological year, increased during autumn and the beginning of winter, and reached the highest values in January/February. Subsequently there was a gradual (in 2020/2021), faster (in 2017/2018 and 2018/2019) or abrupt decrease with a subsequent rebound in spring (2019/2020). The last year (2021/2022) was a more irregular, with relative minima in December, March, and August, and maxima in January and April. In Basin 1, the average NDVI value over the five years was highest and similar for arable plots, woody crops, and pasture areas (0.44–0.46), followed by vineyards (0.38); it exceeded 0.5 in some years. In Basin 2, the values were clearly lower for arable and pasture plots (0.37–0.38), high for woody crops (0.44), and low for vineyards (0.39). Thus, crops having a higher proportion of vegetation cover, (e.g., woody crops) had higher values than others having less cover, (e.g., vineyards). Arable land and grassland showed higher values in Basin 1, again consistent with the longitudinal rainfall gradient (Ruiz Sinoga *et al.*, 2015).

In summary, the evolution of the NDVI through each year leads to soils more protected in Winter and unprotected in Summer against torrential rainfalls, especially in basin 2, in drier years and in those land uses with a lower vegetation cover.

Analysis of monthly and annual rainfall

Table 10 and *Table 11* show the monthly precipitation for the period 2017–2022 and the annual mean for each station. In the western basin (Basin 1, Station 43), the average annual precipitation was 341 mm, which is less than the average for the previous 30 years (385 mm).

Table 8 – Monthly and annual NDVI in Basin 1

	MONTHLY NDVI												ANNUAL NDVI
Year	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**Julia**	**August**	**Average**
2021/22	0.373	0.371	0.347	0.284	0.403	0.337	0.292	0.394	0.433	0.386	0.334	0.294	0.354
2020/21	0.362	0.343	0.378	0.508	0.511	0.520	0.501	0.485	0.502	0.465	0.357	0.374	0.442
2019/20	0.367	0.411	0.414	0.465	0.502	0.539	0.386	0.457	0.440	0.397	0.376	0.367	0.427
2018/19	0.344	0.374	0.471	0.567	0.566	0.545	0.463	0.428	0.404	0.360	0.348	0.311	0.432
2017/18	0.368	0.399	0.375	0.482	0.556	0.510	0.475	0.455	0.435	0.365	0.354	0.348	0.427
												Average	0.416

Table 9 – Monthly and annual NDVI in Basin 2

	MONTHLY NDVI												ANNUAL NDVI
Year	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**August**	**Average**
2021/22	0.366	0.336	0.275	0.302	0.438	0.378	0.370	0.431	0.377	0.323	0.264	0.240	0.342
2020/21	0.291	0.299	0.358	0.462	0.466	0.491	0.481	0.411	0.413	0.397	0.266	0.296	0.386
2019/20	0.316	0.348	0.379	0.446	0.491	0.536	0.485	0.436	0.376	0.339	0.291	0.301	0.395
2018/19	0.261	0.316	0.420	0.523	0.532	0.540	0.434	0.383	0.341	0.276	0.272	0.242	0.378
2017/18	0.252	0.317	0.384	0.430	0.458	0.473	0.477	0.423	0.332	0.258	0.253	0.253	0.359
												Average	0.372

In the eastern basin (Basin 2, Station 44), the average annual precipitation was 251 mm, which is also lower than the average for the last 30 years (299 mm).

The highest monthly rainfall was recorded in March, October and November, with the highest values for basins 1 and 2 occurring in March 2017/2018 (230 mm and 141 mm, respectively). The summer months had the lowest average rainfall, with values equal to or close to 0 in both basins and consistent with this xeric period for the soils.

The same rainfall patterns occurred from 2017 to 2021, involving more or less significant rainfall in autumn–winter, reaching a peak in October, a decrease at the end of winter, and a subsequent decrease to zero values in March. In some years there were more or less pronounced or extensive peaks in spring, and practically zero values in summer, consistent with the typical rainfall pattern for the Mediterranean coast (Ruiz Sinoga *et al.*, 2010).

In general terms, Basin 1 had the highest mean annual rainfall (459 mm in 2019/2020), while in Basin 2 the highest annual rainfall was only 348 mm. The lowest annual precipitation values were recorded in 2021/2022 (Basin 2: 101 mm; Basin 1: 102 mm), these levels were lower than the previous historical minimum 1994/1995 (108 and 111 mm, respectively)

Correlation analysis between NDVI and rainfall

Relationships between the mean values for NDVI and precipitation were observed, starting with the year (2021/2022), which had the lowest precipitation and the lowest NDVI value in each basin.

However, the other years showed similar NDVI (0.43–0.44 in Basin 1 and 0.37–0.39 in Basin 2), even though significantly different precipitations levels were recorded (349–549 mm and 235–248 mm, respectively). Over the five years, the average rainfall differed by almost 100 mm between the two basins (341.26 mm and 251.38 mm, respectively), and there was a slight difference (0.5) in NDVI values (0.416 and 0.372, respectively); Basin 1 always had the highest values for these variables.

The relationship was clearer in the evolution throughout the year. Thus, the increase in NDVI in the autumn–winter months to a maximum in January corresponded to the autumn rains that occurred in most year. Even in years having more irregular rainfall (2021/2022 when there was hardly any precipitation, or 2019/2020, when it occurred later), were observed in the maxima values.

A delay of approximately 1–2 months between rainfall and the response to rainfall (NDVI) was observed in all cases; thus, if the maximum rainfall generally occurred in November–December, the maximum NDVI occurred in January–February.

In the second part of the year, after the maximum, the decrease in NDVI from spring to summer was because of the lower amount of rainfall at this time, although the years having the highest rainfall peak in spring (2017/2018, 2019/2020 and 2020/2021), maintained the highest NDVI values in spring, especially in 2020/2021 where the values remain relatively high until June.

Table 10 – Monthly and Annual Rainfall of Station 43.

Monthly precipitation (mm)													Prec. annual
Year	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**August**	**Average**
2021/22	9.80	4.10	1.40	20.40	3.20	3.70	35.60	11.30	6.40	1.60	0.80	4.10	102.40
2020/21	19.60	39.60	60.80	0.60	75.90	18.30	12.00	73.40	73.50	0.80	0.00	0.20	374.70
2019/20	54.50	4.20	39.40	50.70	71.60	1.00	162.80	43.20	31.00	0.00	0.00	0.70	459.10
2018/19	10.80	177.00	99.60	3.40	1.10	13.60	13.10	29.10	0.00	0.00	0.00	1.40	349.10
2017/18	0.40	36.10	48.90	10.00	19.90	27.70	230.00	41.40	6.60	0.00	0.00	0.00	421.00
												Average	341.260

Table 11 – Monthly and Annual Rainfall of Station 44.

Monthly precipitation (mm)													Prec. annual
Year	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**August**	**Average**
2021/22	0.60	0.80	10.40	22.90	3.20	3.70	35.60	11.30	6.40	1.60	0.80	4.10	101.40
2020/21	6.40	16.80	40.20	0.00	44.70	19.90	21.10	30.80	34.30	6.80	0.00	14.50	235.50
2019/20	5.00	6.20	63.10	15.30	42.80	0.40	103.40	27.80	19.10	0.00	0.00	0.00	283.10
2018/19	47.90	133.00	114.10	2.10	0.90	14.00	4.60	27.60	0.00	0.00	0.00	4.00	348.20
2017/18	0.20	25.90	38.70	5.30	42.90	14.00	141.30	18.20	2.20	0.00	0.00	0.00	288.70
												Average	251.380

A correlation analysis (Pearson correlation coefficient) was carried out between the monthly NDVI and precipitation in each basin, using comparison of the one- and two- month moving averages before and after each NDVI value with the corresponding cumulative values of precipitation (*Table 12*).

With some exceptions the correlations between NDVI and monthly precipitation were not statistically significant values. The correlations were more significant if a three-month moving average and sum were made (i.e., the month before, the month in question, and the month following), and more so if five months were considered (the two months before, the month in question, and the two months following). This confirms that the NDVI response to prior rainfall had a lag period (1−2months), although there were years in which this correlation did not occur (2018/2019 and 2021/2022) because these were drier years and had a more irregular distribution of rainfall.

However, the time-lag effects are less considered, which tends to increase uncertainty in the response of each territory (Wu *et al.*, 2018). In general, Li and Qu did not observe an apparent delay in the response of vegetation to precipitation in most locations in the northern hemisphere, although in the southern Mediterranean basins analyzed the estimated delay has been 1-2 months in the rainiest years. Thus, rainfall regime has a clear influence in NDVI values as had been already demonstrated in previous works in arid or semiarid regions (Davenport and Nicholson, 1993; Fabricante *et al.*, 2009; Georganos *et al.*, 2017; Garai *et al.*, 2022), although in this work a lag period of 1-2 months has been observed between the rainfalls and NDVI peaks.

Thus, the NVDI has lower average values in drier months (summer) than wetter ones (winter), especially in the drier years (such as 2021-2022) and basin 2 that present lower average rainfalls. Since the NDVI can be considered among other ones a factor related to vegetation cover (Jiang *et al.*, 2006; Gao *et al.*, 2020; Tenreiro *et al.*, 2021), these conditions in which the NDVI is lower are more susceptible to water erosion processes originated with torrential rainfalls.

Table 12 – Pearson's correlation coefficient

Year	Month average	Month average, 1 month before and 1 month after	Month average, 2 months before and 2 months after
		Basin 1	
2021/22	-0.477	0.006	-0.037
2020/21	0.222	0.582	0.649
2019/20	-0.048	0.717	0.857
2018/19	-0.091	0.033	0.388
2017/18	0.294	0.670	0.860
		Basin 2	
2021/22	0.078	0.682	0.855
2020/21	0.363	0.845	0.890
2019/20	0.461	0.820	0.943
2018/19	-0.118	-0.010	0.302
2017/18	0.588	0.849	0.942

These extreme rainfalls, that could increase in next years as a consequence of climate change (Viceto *et al.*, 2017; Doblas-Reyes *et al.*, 2021), occurred frequently at the end of Summer or beginning of Autumn, when the vegetation cover is less developed.

CONCLUSIONS

Differences were found in current land uses and the evolution of land use over the last three decades in the two study basins, despite their proximity. There has been a continuous evolution of irrigated crops, more specifically where there is less vegetation cover and less rainfall, and consequently there has been a gradual disappearance of rainfed crops. In both basins the updated MUCVA classification showed an increase in the anthropic areas, characterized by greater urban expansion (or soil sealing) and an increase in irrigated areas, involving both greenhouses and subtropical crops, especially in the drier area. There was a clear contrast between Basin 1, a typical traditional Mediterranean basin, and Basin 2, where there has been development of more competitive crops adapted to the economic needs of the area.

The changes in land use, especially those in which a loss of vegetation cover could make the study are more susceptible to erosion processes. The vegetation cover can be reduced not only by human action but the changes in the general rainfall regime towards a drier one. Moreover, torrential rainfall events, frequent in Mediterranean basins and that can be-come extreme in next years related to climatic change, can increase this susceptibility.

The MUCVA methodology used as a reference is relatively complete, having a longer period of comparison and a larger scale than for other methodologies in Spain in general, and in Andalusia in particular, although it has not been updated since 2007.

With regard to rainfall events, both basins had a large number of torrential events, resulting in an increase in water erosion in both areas. This is increasing impoverishing the soil, considerably reducing soil quality, and making the soil more vulnerable and susceptible to the impact of raindrops on the soil, especially on steep slopes.

It was observed that the months having the highest rainfall were not necessarily those with the greatest water erosion, which is more closely linked to rainfall intensity. Moreover, the months having the highest rainfall (March, October, and November) coincided with the months having the most 10-min torrential events (in November). In contrast, March had the highest rainfall, but only one torrential event was recorded in Basin 2. A direct correlation of the NDVI with monthly rainfall was observed, especially in the first months of the year and in spring some years; this depended on the precipitation regime and the delay period (1–2 months) following rainfall, as a result of vegetative growth (because of the uptake of moisture by the vegetation).

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REFERENCES

Acero, F.J.; García, J.A.; Gallego, M.C. Peaks-over-threshold study of trends in extreme rainfall over the Iberian Peninsula. *Journal of Climate*. **2011**, 24, 1089–1105. https://doi.org/10.1175/2010JCLI3627.1.

AEMET. Brief descriptive guide to the meteorological phenomena included in the Singular Atmospheric Observations Notification System (in *Spanish*), SINOBAS. In Agencia Estatal de Meteorología (Eds.). Ministerio de Agricultura, Alimentación y Medio Ambiente, 2013.

Airbus | Pioneering sustainable aerospace. (2021, 11 june). Airbus. https://www.airbus.com/en.

Baldi, G.; Nosetto, M.D.; Aragón, R.; Aversa, F.; Paruelo, J.M.; Jobbágy, E.G. Long-term satellite NDVI data sets: Evaluating their ability to detect ecosystem functional changes in south america. *Sensors*. **2008,** 8, 5397-5425. http://doi:10.3390/s8095397.

Bannari, A.; Morin, D.; Bonn, F.; Huete, A.R. A review of vegetation indices. *Remote Sensing Reviews*. **1995**, 13, 95-120. https://doi.org/10.1080/02757259509532298.

Davenport, M.L.; Nicholson, S.E. On the relation between rainfall and the Normalized Difference Vegetation Index for diverse vegetation types in East Africa. *International Journal of Remote Sensing*. **1993**, 14, 2369-2389. http://doi.org/10.1080/01431169308954042.

De Castro, M.; Martin Vida, J.; Alonso, S. Clima Spaniei: trecut, prezent și scenarii climatice pentru secolul 21 (in *Spanish*). In Ministerio de Medio Ambiente (Eds.), Evaluación preliminar de los impactos en España por efecto del cambio climático (pp. 1–64). Universidad de Castilla La Mancha, Centro de Publicaciones, Secretaría General Técnica, Minsiterio de Medio Ambiente, 2005.

Doblas-Reyes, F.J.; Sörensson, A.A.; Almazroui, M.; Dosio, A.; Gutowski, W.J.; Haarsma, R.; Hamdi, R.; Hewitson, B.; Kwon, W.-T.; Lamptey, B.L.; Maraun, D.; Stephenson, T.S.; Takayabu, I.; Terray, L.; Turner, A.; Zuo, Z. Linking Global to Regional Climate Change. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate

Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2021, 1363–1512, https://doi.org/10.1017/9781009157896.012.

Douville, H.; Raghavan, K.; Renwick, J.; Allan, R.P.; Arias, P.A.; Barlow, M.; Cerezo-Mota, R.; Cherchi, A.; Gan, T.Y.; Gergis, J.; Jiang, D.; Khan, A.; Pokam Mba, W.; Rosenfeld, D.; Tierney, J.; Zolina, O. Water Cycle Changes. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 2021, 1055–1210. https://doi.org/10.1017/9781009157896.010.

Encina Rojas, A.; Ibarra, J. Soil degradation and its effects on the population (in *Spanish*). *Población y Desarrollo*. **2003**, 25, 5–10.

Fabricante, I.; Oesterheld, M.; Paruelo, J.M. Annual and seasonal variation of NDVI explained by current and previous precipitation across Northern Patagonia. *Journal of Arid Environments.* **2009**, 73, 745–753.

FAO. United Nations Food and Agriculture Organization, (accessed on 14 December 2022). https://www.fao.org/home/es.

Ferrari, E.; Caloiero T.; Coscarelli, R. Influence of the North Atlantic Oscillation on winter rainfall in Calabria (southern Italy). *Theoretical and Applied Climatology*. **2013**, 114, 479–494. http://dx.doi.org/10.1007/s00704-013-0856-6.

Gao, L.; Wang, X.; Johnson, B.A.; Tian, Q.; Wang, Y.; Verrelst, J.; Mu, X.; Gu; X. Remote sensing algorithms for estimation of fractional ve-getation cover using pure vegetation index values: A review. *ISPRS Journal of Photogrammetry and Remote Sensing*. **2020**, 159, 364–377.

Garai, S.; Khatun, M.; Singh, R. ***et al.*** Assessing correlation between Rainfall, normalized difference Vegetation Index (NDVI) and land surface temperature (LST) in Eastern India. *Safety in Extreme Environments*. **2022**, 4, 119–127. https://doi.org/10.1007/s42797-022-00056-2.

Georganos, S.S.; Abdi, A.M.; Tenenbaum, D.E.; Kalogirou, S. Examining the NDVI-rainfall relationship in the semi-arid Sahel using geographically weighted regression. *Journal of Arid Environments*. **2017**, 146, 64–74. http://doi.org/10.1016/j.jaridenv.2017.06.004.

Hennessey, K.J.; Pittock, A.B. Greenhouse warming and threshold temperature events in Victoria, Australia. *International Journal of Climatology*. **1995**, 15, 591–612. http://dx.doi.org/10.1002/joc.3370150602.

Hicke, J.A.; Asner, G.P.; Randerson, J.T.; Tucker, C.; Los, S.; Birdsey, R.; Field, C. Trends in North American net primary productivity derived from satellite observations, 1982-1998. *Global Biogeochemical Cycles*. **2002**, 16, 2-1-2-14.

http://doi:10.1029/2001gb001550.

Hueso González, P; Martínez Murillo, J.F.; Muñoz Rojas, M. The role of Organic amendments in drylands restoration. *Current Opinion in Environmental Sciences and Health*. **2018**, 5, 1–6. https://doi.org/10.1016/j.coesh.2017.12.002.

I Clar, A.J. Clima insulelor Baleare. Mediteranenie și singularitate (*in Spanish*). *Treballs de Geografia*. **1988**, 39, 39–43.

IPCC. Climate change 2001: the scientific basis. In J. T. Houghton, Y., Ding, D. J. Griggs, M., Noguer, P. J., van der Linden, X. Dai, K. Maskell, C. A. Johnson (Eds.), Contribution of working group I to third assessment report of the intergovernmental panel on climate change, Cambridge University Press. pp. 881, United Kingdom and New York, NY, USA. 2001.

IPCC. Climate change 2007: the physical science basis. In: S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, H.L. Miller (Eds.), Contribution of Working Group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, 2007.

IPCC. Fifth Assessment Report. IPCC. 2014. Retrieved from http://ipcc.ch/report/ar5.

IPCC. Climate Change and Land. An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Summary for policymakers. WMO-UNEP, 2019, 41.

Jiang, Z.; Huete, A.R.; Chen, J.; Chen, Y.; Li, J.; Yan, G.; Zhang, X. Analysis of NDVI and scaled difference vegetation index retrievals of vegetation fraction. *Remote Sensing of Environment*. **2006**, 101, 366–378. http://doi.org/10.1016/j.rse.2006.01.003.

De Jong, R.; Schaepman, M.E.; Furrer, R.; de Bruin, S.; Verburg, P.H. Spatial relationship between climatologies and changes in global vegetation activity. *Global Change Biology*. **2013**, 19, 1953–1964. http://doi:10.1111/gcb.12193.

Li, X.; Qu, Y. Evaluation of vegetation responses to climatic factors and global vegetation trends using GLASS LAI from 1982 to 2010. *Canadian Journal of Remote Sensing*. **2018**, 44, 357–372. http://doi.org/10.1080/07038992.2018.1526064.

López Bermúdez, F.; Romero Díaz, M.A. Genesis and consequences of high intensity erosion in the Mediterranean región (in *Spanish*). *Cuadernos de Investigación Geográfica*. **1993**, 18–19, 7–28.

Martín Vide, J.; Llasat, M.C. Torrential rainfall in Catalonia (in *Spanish*). *Serie Geográfica*. **2000**, 9, 17–26.

Martín Vide, J. Torrential rainfall in Spain (in *Spanish*). Revista geográfica Norba, 1989, 6–7, 63–70. Retrieved from https://www.researchgate.net/publication/41091147_Precipitaciones_torrenciales_en_Espana.

Martínez Navarro, J.M. Territorial management of the anthropic risk of forest ignition in Castilla-La Mancha (in *Spanish*). PhD Thesis. Boletín de la Asociación de Geógrafos Españoles 76, 2018, 571–576.

National Geographic Institute. High resolution Information System of Land Occupancy in Spain (in *Spanish*). In Land Occupation Information System in Spain (SIOSE). National Technical Team, 2022. http://www.siose.es/SIOSEtheme-theme/documentos/pdf/Documento_Tecnico_SIOSE_AR_v1.3.pdf.

Olcina Cantos, J.; Rico Amorós, A.M. Studies on torrential rains and floods in the province of Alicante (1982-1999) (in *Spanish*). *Serie Geografica*. **2000,** 9, 71–93.

Open Access Hub. https://scihub.copernicus.eu/, (accesed on 10 January 2023).

Red de Información Ambiental de Andalucía - Environmental Portal of Andalusia (in *Spanish*). https://www.juntadeandalucia.es/medioambiente/portal/acceso-rediam.

Red Hidrosur. http://www.redhidrosurmedioambiente.es/saih/, (accesed on 10 January 2023).

Rodrigo, F.S. Changes in the probability of extreme daily precipitation observed from 1951 to 2002 in the Iberian Peninsula. *International Journal of Climatology*. **2010**, 30, 1512–1525. https://doi.org/10.1002/joc.1987.

Rouse, J.W.; Haas, R.W.; Schell, J.A.; Deering, D.W.; Harlan, J.C. Monitoring the vernal advancement and retrogradation (Greenwave effect) of natural vegetatioa NASA/GSFCT Type III Final Report, Greenbelt, MD, USA, 1974.

Ruiz Sinoga, J.D.; Romero Diaz, A.; Martínez Murillo, J.F.; Gabarrón Galeote, M.A. Incidence of rainfall dynamics on soil degradation. South of Spain (in *Spanish*). Boletín de Asociación de Geógrafos Españoles. **2015**, 68, 177–204. https://doi.org/10.21138/bage.1858

Ruiz Sinoga, J.D.; García Marín, R.; Martínez Murillo, J.F.; Gabarron Galeote, M.A. Precipitation dynamics in southern Spain: *Trends and cycles. International Journal of Climatology*. **2010**, 31, 2281–2289. http://dx.doi.org/10.1002/joc.2235.

Santos Deltell, M.J. Study of extraordinary rainfall (100 mm 24 h^{-1}) in the province of Alicante, 1914-1989 (in *Spanish*). In: Sociedad y Territorio XII Congreso Nacional de Geografía. Universidad de Valencia y Asociación de Geógrafos Españoles, 1991, 205–214, Valencia.

Senciales-González, J.M.; Ruiz-Sinoga, J.D. Features of weather types involving heavy rainfall along the southern Spanish Mediterranean. *Cuadernos De Investigación Geográfica*. **2021**, 47, 221–242. https://doi.org/10.18172/cig.4765.

Senciales González, J. M., Ruiz Sinoga, J. D. Spatio-temporal analysis of torrential rains in the city of Malaga (in *Spanish*). Boletín de la Asociación de Geógrafos Españoles. **2013**, 61, 7–24. http://dx.doi.org/10.21138/bage.1533

Seneviratne, S.I.; Zhang, X.; Adnan, M.; Badi, W.; Dereczynski, C.; Di Luca, A.; Ghosh, S.; Iskandar, I.; Kossin, J.; Lewis, S.; Otto, F.; Pinto, I.; Satoh, M.; Vicente-Serrano, S.M.; Wehner, M.; Zhou, B. Weather and Climate Extreme Events in a Changing Climate. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2021, 1513–1766, https://doi.org/10.1017/9781009157896.013.

SIGPAC. Geographic Information System for Agricultural Plots (in *Spanish*). https://www.mapa.gob.es/es/agricultura/temas/sistema-de-informacion-geografica-de-parcelas-agricolas-sigpac-/ (accesed on 15 December 2022)

Sillero-Medina, J.A.; Martínez-Murillo, J.F.; Ruiz-Sinoga, J.D. Increased rainfall erosivity and its effects on soil loss estimation: A comparison between two watersheds in southern Spain. *Boletín de la Asociación de Geógrafos Españoles*. **2021,** 89. https://doi.org/10.21138/bage.3077.

Sillero Medina, J.A.; Hueso González, P.; Ruiz Sinoga, J.D. Geomorphological precipitation as a key element in the modeling of the Mediterranean landscape (in *Spanish*). *Boletín de la Asociación de Geógrafos Españoles*. **2019**, 82, 1–40. http://dx.doi.org/10.21138/bage.2780.

Sinoga, J.D.R.; Martínez-Murillo, J.F. Eco-hydrological response of soils in abandoned fields (southern Spain) (in *Spanish*). *Cuadernos de investigación geográfica/Geographical Research Letters*. **2012,** 38, 31-52. https://dialnet.unirioja.es/descarga/articulo/4002953.pdf.

Tenreiro, T.R.; García-Vila, M.; Gómez, J.A.; Jiménez-Berni, J.A., Fereres, E. Using NDVI for the assessment of canopy cover in agricultural crops within modelling re-search. *Computers and Electronics in Agriculture*. **2021**, 182, 106038.

Viceto, C.; Martinho, M.-A. Future climate change of stability indices for the Iberian Peninsula. *International Journal of Climatology*. **2017**, 37. https://doi.org/4390-4408.10.1002/joc.5094.

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