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Bioclimatic drought trend study through the application of the ombroxeric index. A case study: the province of León (Spain)

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ABSTRACT
The ombroxeric index (OXI), a drought-indicative bioclimatic index based on the Rivas-Martínez Worldwide Bioclimatic Classification System (WBCS), was used in this work to establish the ombroxericity trends in a defined study area: the province of Leon (Spain). On the basis of large time-scale climatological gridded databases (MOPREDAS and MOTEDAS), with data from 1951 to 2010 at monthly, seasonal an annual study level, a Mann-Kendall test-based trend analysis was carried out and a geostatistical interpolation procedure, Empirical Bayesian Kriging (EBK), was applied. Statistically significant increases were revealed in the months of March and June, as well as in the summer period. These increments are greater in the southernmost areas and could be related with changes in some teleconnection patterns. With this up-to-date approach, besides being aware of the direct bioclimate-altering consequences of the climate change, the prediction of the implications in the vegetation is made possible, due to the typological-predictive character of the model of climate-vegetation reciprocity provided by the WBCS.

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1. Introduction

Bioclimatology (or Phytoclimatology) is the science that studies the relationships between climate and plant chorology (Rivas-Martínez et al., 2017). One of the factors that influences the development and distribution of plant communities is the water availability. The study of its abundance in the environment and, especially, its scarcity, is undeniably necessary to understand how the flora and vegetation of a territory has been constituted. This need is accentuated by the current context, in which climate change is causing a measurable increase in temperatures and a change in the distribution and amount of precipitation (del Río et al., 2005; IPCC, 2014; Mourato et al., 2010). These variations directly affect the water availability in the environment.

According to the World Meteorological Organization (2018), drought is a transitory natural hazard, consisting of a temporary but significantly long-lived absence of water. Its study has shifted in perspective since the first aridity indices were developed in the first half of the last century. Their aim was to characterise a territory from the point of view of water availability and to establish typological classifications. This approach can be referred as a 'classical approach'. Among these indices may be mentioned some based on arithmetic calculations with few parameters, such as Lang's pluviofactor (Lang, 1915). This index consists of a ratio between annual precipitation (in mm) and annual mean temperature (in °C) that, despite its simplicity, has been proven to be useful in predicting vegetation types corresponding to large regions (Vlăduţ et al., 2017) and its strong statistical correlations with plant physiology indicators (Piermattei et al., 2014). Other remarkable indices that attempt to correct the shortcomings of Lang's pluviofactor are Köppen's index (1923) or de Martonne's aridity index (1926). However, to the best of our knowledge, these indices have not been used as a basis for finding trends in the drought of the territory, but only to classify it according to its aridity.

In recent years, many studies have endeavour to establish connections between climate change and drought phenomena, as well as seeking the trends that this event has followed in recent decades (Gaitán et al., 2020; Tsiros et al., 2020; Vicente-Serrano et al., 2014; Zhao et al., 2020). Then, in addition to carrying out spatial studies, the aim of this 'modern approach', in contrast to the classical one, is to be able to predict how water scarcity phenomena will evolve in the

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coming years. For this purpose, new indices have been developed, many of them based on the Standardised Precipitation Index (SPI), developed by McKee in 1993 (Mckee et al., 1993). One of this SPI-based indexes is the Standardised Precipitation-Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010), widely used in the study of spatio-temporal patterns of drought phenomena (Sivakumar et al., 2019; Tirivarombo et al., 2018). Other novel index used in monitoring periods of water scarcity is the Keetch-Byram Drought Index (KBDI) (Garcia-Prats et al., 2015). However, its main usefulness is given by the strong correlation between the KBDI's value and the attributes of the wildfires that follow dry periods (Gomes et al., 2020; Zhao & Liu, 2021). Also noteworthy is the Temperature-Vegetation-Soil Moisture-Precipitation Drought Index (TVMPDI), whose determination method uses satellite images to obtain data of soil characteristics based on reflectance (Amani et al., 2017; Mehravar et al., 2021).

The modern approach to drought monitoring has been applied for economic purposes, in natural hazards prevention and in biological conservation (Desbureaux & Damania, 2018; Shrestha et al., 2021; Xu et al., 2021). Nevertheless, it is difficult to predict with certainty what the vegetation of a territory will be like on a temporal scale. Accordingly, in this work we aimed to use a recently developed drought-indicative bioclimatic index: the ombroxeric index (OXI) (del Río et al., 2018a). The ombroxeric index is based on the concept of ombroxericity: a condition of the territory characterised from the ombrothermic point of view, which can manifest itself in more or less humid territories, depending on the level of study (monthly, seasonal or annual) (del Río et al., 2018a). That concept is based on the Rivas-Martínez Worldwide Bioclimatic Classification System (WBCS), whose fundamental principle is to establish a reciprocal relationship between bioclimatic indices, vegetation series and plant chorology (Rivas-Martínez et al., 2011). Therefore, the finding of trends in the indices proposed by these authors can pave the way for the establishment of further predictions about what the future vegetation of a specific region will be like, and how it will be variate as a consequence of climate change.

The implementation of the ombroxeric index has a clear advantage compared to the direct application of another thermo-pluvial factors based on annual computation. These latter indexes merely characterise a region as hyperhumid, humid, dry, etc., but do not assume that a region which is annually wet from the ombrothermal perspective, can be periodically dry. If our eventual purpose is to predict future changes in vegetation, this fact is highly relevant. For example, beech forests require rainfall throughout the year, particularly in the summer season (del Río et al., 2018b; Fotelli et al., 2009). Then, an annually humid region can be stated as suitable for the establishment of a beech forest regardless of the existence of summer drought. However, a substitution of beech for birch forest is noted in those areas of the Leon province with a humid-hyperhumid ombrotype and where rainfall decreases in summer (Albaladejo Fresnadillo et al., 2010). Therefore, vegetation of a humid location can be replaced by the prevalence of bioclimatic drought in certain months or seasons, fact that justifies the application and usefulness of the ombroxeric index.

The aim of this paper is to analyse the ombroxericity trends of a case study area in order to implement a trend-analysis model based on a bioclimatic and cartographic approach. As far as we are aware, there are not studies in which a bioclimatic approach is applied in xericity trend analysis. Further, in this work a bioclimatic drought index is applied at monthly, seasonal and annual level, which was also not found in the scientific literature to the best of our knowledge.

2. Materials and methods

2.1. Study area

The study area selected for this work is the province of León, which belongs to the Autonomous Community of Castilla and León, located in the northwest of the Iberian Peninsula (42° 3'27″ N–43° 14'11″ N and 4° 47'25″ W–7° 2'47″ W). It covers an area of 15,581 km^2 and its administrative borders, as well as its relief, hydrography and bioclimatology, are represented in Figure 1. In terms of bioclimatology, the dominant bioclimate is the Mediterranean pluviseasonal oceanic (Mepo), present in the centre-south of the province, as well as in El Bierzo. In more northern latitudes and in the Montes of León, as the altitude increases, there is a transition towards a Temperate oceanic (Teoc) bioclimate, with a great prominence of the submediterranean (sbm) bioclimatic variant (Rivas-Martínez et al., 2017).

2.2. Data set

The dataset used is based on the gridded databases MOTEDAS and MOPREDAS, developed and provided by González-Hidalgo et al. (2011, 2015). After a suitable optimisation and organisation, our final dataset contains monthly, seasonal and annual mean temperature and precipitation data for 170 localities in the province of León for the period 1951–2010. The seasons of the year have been considered according to the standard for the northern hemisphere: winter = DJF (December, January and February), spring = MAM (March, April and May), summer = JJA (June, July and August) and autumn = SON (September, October and November).

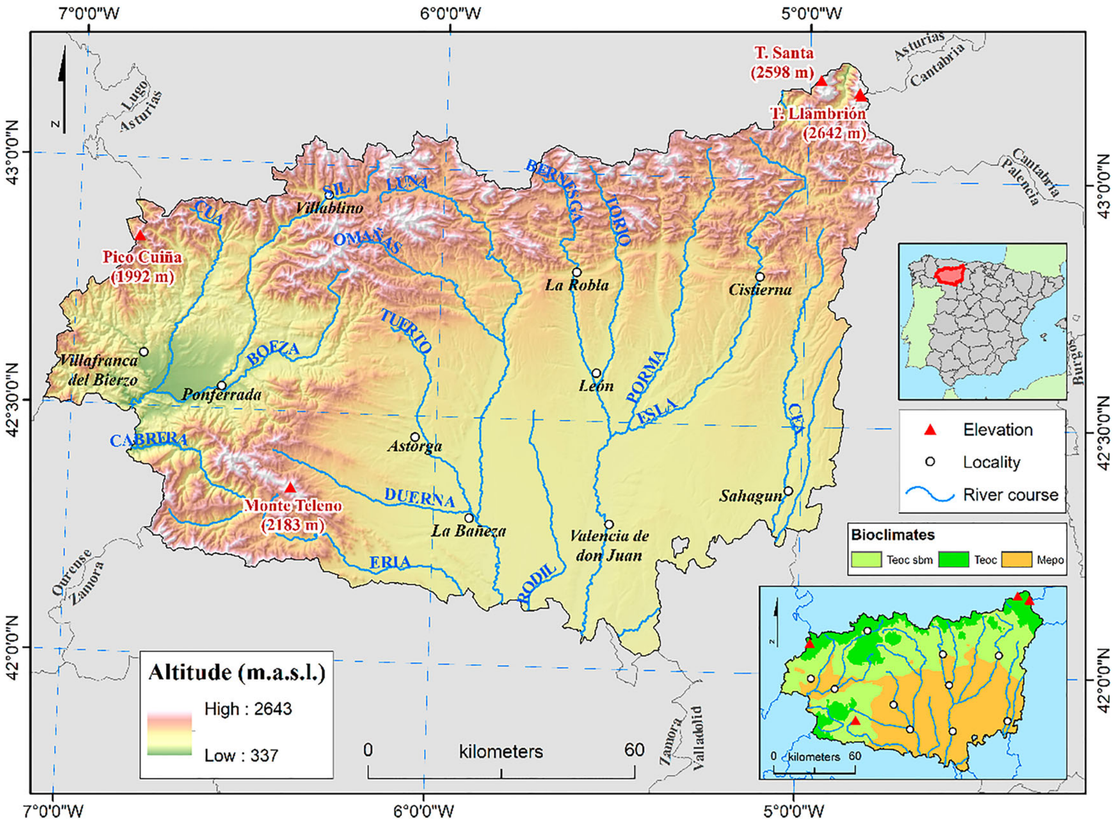

Figure 1. Administrative borders, larger localities, highest elevations and major river courses of the province of Leon (Spain). A bioclimatic map is included; Teoc: Temperate oceanic, Teoc sbm: Temperate oceanic with submediterranean bioclimatic variant, Mepo: Mediterranean pluviseasonal oceanic.

2.3. Ombroxeric index (OXI)

The ombroxeric index (OXI), which expresses the ombroxericity or bioclimatic drought of a given territory at monthly, seasonal or annual level, is defined at monthly study level by the following formula (del Río et al., 2018a):

$$\mathrm{OXI}i = 360 - (100 * Ioi)$$

where OXI_i and Io_i are the ombroxeric index and the ombrothermic index of month i ($i = 1, \ldots, 12$), where $i = 1$ January and $i = 12$ December. The monthly ombrothermic index (Io_i) is defined as the ratio between precipitation and mean temperature of month i, provided that the latter is greater than 0°C (del Río et al., 2018a). The threshold value to consider that a locality shows monthly bioclimatic drought is 0. Then, if the Io_i of this locality is equal or higher than 3.6, the OXI_i will be a negative value, so it is safe to say that there is no evidence of ombroxericity at this site. Hence, all OXI_i negative values have been considered as 0.

Based on the monthly ombroxeric index, both the seasonal ombroxeric indices and the annual ombroxeric index can be defined by the following formulae:

$$\text{Annual ombroxeric index } (\mathrm{OXI}_a){:}\mathrm{OXI}_a = \sum_{i=1}^{12} \mathrm{OXI}_i$$

$$\text{Winter ombroxeric index } (\mathrm{OXI}_w){:}\mathrm{OXI}_w = \mathrm{OXI}_{12} + \mathrm{OXI}_1 + \mathrm{OXI}_2$$

$$\text{Spring ombroxeric index } (\mathrm{OXI}_{spr}){:}\mathrm{OXI}_{\mathrm{spr}} = \mathrm{OXI}_3 + \mathrm{OXI}_4 + \mathrm{OXI}_5$$

$$\text{Summer ombroxeric index}(\mathrm{OXI}_{\mathrm{sum}}){:}\mathrm{OXI}_{\mathrm{sum}} = \mathrm{OXI}_6 + \mathrm{OXI}_7 + \mathrm{OXI}_8$$

$$\text{Autumn ombroxeric index}(\mathrm{OXI}_{\mathrm{aut}}){:}\mathrm{OXI}_{\mathrm{aut}} = \mathrm{OXI}_9 + \mathrm{OXI}_{10} + \mathrm{OXI}_{11}$$

All the preceding calculations have been applied to our dataset.

The classification criteria for the ombroxeric index is given in Table 1. The types of ombroxericity (ombroxerotypes) are shown, with their respective ombroxerotypic levels and the value of the ombroxeric index at monthly, seasonal and annual study levels.

2.4. Trend analysis

On the dataset with OXI values for the entire study period at the three designated study levels (monthly, seasonal and annual) the Mann-Kendall statistical test (MKT) was applied in each locality (Mann, 1945). This statistical test has been used due to: (i) it

Table 1. Ombroxerotypes, with their respective ombroxerotypic levels, for monthly, seasonal and annual study levels.

Ombroxerotypes	Ombroxerotypic levels	Ombroxeric index value		
		Monthly (OXI_i)	Seasonal (OXI_{spr}, OXI_{sum}, OXI_{aut}, OXIw)	Annual (OXI_a)
Dry	Upper weak dry	1–40	1–120	1–480
	Upper strong dry	40–80	120–240	480–960
	Lower weak dry	80–120	240–360	960–1440
	Lower strong dry	120–160	360–480	1440–1920
Semiarid	Upper weak semiarid	160–180	480–540	1920–2160
	Upper strong semiarid	180–210	540–630	2160–2520
	Lower weak semiarid	210–240	630–720	2520–2880
	Lower strong semiarid	240–260	720–780	2880–3120
Arid	Upper weak arid	260–280	780–840	3120–3360
	Upper strong arid	280–290	840–870	3360–3480
	Lower weak arid	290–310	870–930	3480–3720
	Lower strong arid	310–320	930–960	2720–3840
Hyperarid	Upper hyperarid	320–330	960–990	3840–3960
	Lower hyperarid	330–340	990–1020	3960–4080
Ultrahyperarid	Upper ultrahyperarid	340–350	1020–1050	4080–4200
	Lower ultrahyperarid	350–360	1050–1080	4200–4320

Source: del Río et al. (2018a).

does not assume any type of data distribution; (ii) it accepts direct application in climatological parameters (Ribeiro et al., 2016) and (iii) it has recently been applied in other works trying to find trends in drought and aridity, and it is recommended for these purposes by the World Meteorological Organization (Somée et al., 2013; Zhao et al., 2019). The mathematical basis of the test was considered as in del Río et al. (2005) or in Zhao et al. (2019), being the null hypothesis the inexistence of trends, which is rejected at Z-value = 1.96 ($\alpha = 0.05$), with a statistical significance of $p = 0.05$.

Both slope values (m; rate at which ombroxericity is increasing or decreasing) and p-values for each of the 170 locations have been interpolated using Empirical Bayesian Kriging (EBK) (Krivoruchko & Gribov, 2019), a geostatistical interpolation technique widely used in recent years for its accuracy, especially in modelling climatological variables (Ali et al., 2021; Gupta et al., 2017; Li et al., 2020). Its implementation here is not only encouraged by the scientific literature, but has been supported by the nature of our data. Three major assumptions must be taken into consideration when kriging is applied: (i) Gaussian data distribution; (ii) stationary data; and (iii) lack of spatial trend (Gribov & Krivoruchko, 2020; Handcock & Wallis, 1994). However, local variation (non-stationary) in both slope values and p-values is expected in our data due to the ruggedness of the territory. In this context, EBK is specially recommended (de Risi et al., 2021; Gribov & Krivoruchko, 2020; Krivoruchko & Gribov, 2014). To confirm this hypothesis, several kriging models have been tested with cross-validation parameters applied in the same way as in Pellicone et al. (2019) or Ali et al. (2021).

Slope values were represented as isometrical contour which connects localities with the same slope value, while p-values such that $p < 0.05$ were represented as surfaces.

3. Results

3.1. Optimal interpolation method

Three interpolation models are contrasted: Ordinary Kriging (OK), Ordinary Cokriging plus Elevation (COK + E) and Empirical Bayesian Kriging (EBK). Deterministic models, as Inverse Distance Weighting (IDW), were not carried out given their proven poorer performance compared to geostatistical methods (Pellicone et al., 2019; Zimmerman et al., 1999). The results of the interpolation model comparison for Root-Mean-Square Error (RMSE), Root-Mean-Square Standardized Error (RMSSE), and Average Mean Standardized Error (AMSE) are shown in Table 2. As an example, scatter plots for measured versus predicted values of annual slope (m) and p-value for the three models compared are shown in Figure 2. As expected, the EBK is the geostatistical interpolation model that best fits our data. The parameters used in its implementation are shown in Table 3. Good results are also shown by COK + E, but gross underestimates and overestimates are sometimes observed.

3.2. Trends in bioclimatic drought

The ombroxericity trends study map is given in the Main Map and contain the trends analysis at annual, seasonal and monthly study level. Only the periods that evidence bioclimatic drought and trends on it will be represented.

At annual level, there is a general increase in the bioclimatic dryness of the province of León, with a radial gradient that increases from a small nucleus, in the southwest of the province, where the ombroxericity tends to decrease slightly.

At seasonal level, three seasons of the year show trends in ombroxericity: spring and summer, with mostly positive trends, and autumn, with a

Table 2. Root-Mean-Square Error (RMSE), Root-Mean-Square Standardized Error (RMSSE) and Average-Mean Standardised Error (AMSE) in the three selected model for every study period and for the two study variables: slope (*m*) and *p*-value (*p*).

		OK			COK + E			EBK		
		RMSE	RMSSE	AMSE	RMSE	RMSSE	AMSE	RMSE	RMSSE	AMSE
March	*m*	0.085	1.094	0.078	0.086	1.178	0.073	0.083	0.982	0.083
	p	0.100	1.230	0.095	0.106	0.937	0.126	0.098	0.892	0.111
June	*m*	0.081	0.898	0.090	0.078	1.283	0.063	0.077	0.932	0.083
	p	0.018	1.161	0.016	0.0179	0.953	0.019	0.017	0.897	0.016
July	*m*	0.033	1.081	0.030	0.033	0.772	0.042	0.033	0.927	0.034
	p	0.049	1.099	0.045	0.0491	1.513	0.033	0.049	0.905	0.054
August	*m*	0.040	0.980	0.041	0.037	2.052	0.022	0.035	0.773	0.043
	p	0.051	0.821	0.062	0.049	1.079	0.046	0.049	0.938	0.052
Spring	*m*	0.141	0.973	0.148	0.143	1.011	0.144	0.132	0.900	0.145
	p	0.122	0.950	0.129	0.126	0.956	0.132	0.116	0.965	0.121
Summer	*m*	0.178	0.991	0.187	0.187	0.991	0.195	0.175	0.884	0.190
	p	0.067	0.927	0.074	0.068	1.155	0.061	0.067	0.879	0.072
Autumn	*m*	0.116	1.005	0.118	0.120	1.041	0.118	0.115	0.882	0.129
	p	0.113	1.024	0.112	0.113	0.971	0.117	0.112	1.034	0.110
Annual	*m*	0.176	0.915	0.192	0.183	0.948	0.192	0.166	0.918	0.179
	p	0.059	0.810	0.073	0.060	1.018	0.059	0.058	0.988	0.059

predominantly negative trend. Summer is the season with the most noticeable increase in bioclimatic drought, especially in the south-eastern part of the province. In this area, statistically significant increases of more than 2.5 units per year are observed. The area affected by such increases occupies one seventh of the territory. However, it is worth noting a small area, in the west, where ombroxericity tends to decrease. An analysis of the months comprising the summer will be necessary to explain this phenomenon. In spring, a non-significant increase in its ombroxericity is observed both in the south-eastern extreme and in the north-western area. Regarding autumn, the main trend is a decrease in its ombroxericity over most of the study area.

Finally, and in order to understand the variations observed at the seasonal level, we must recourse to an analysis of trends at monthly level. Four months show trends in ombroxericity: March and the summer months (June, July and August). In March, a statistically significant increase in drought is evident in the south-eastern of the study area, coinciding with the lower part of the Duero basin, with increases of up to 0.25 units per year. Further north there is no trend or a decrease in ombroxericity. The summer months show a great disparity between them in the direction and the spatial distribution of their trends. June is the month with the most statistically significant increase in ombroxericity, with more than a

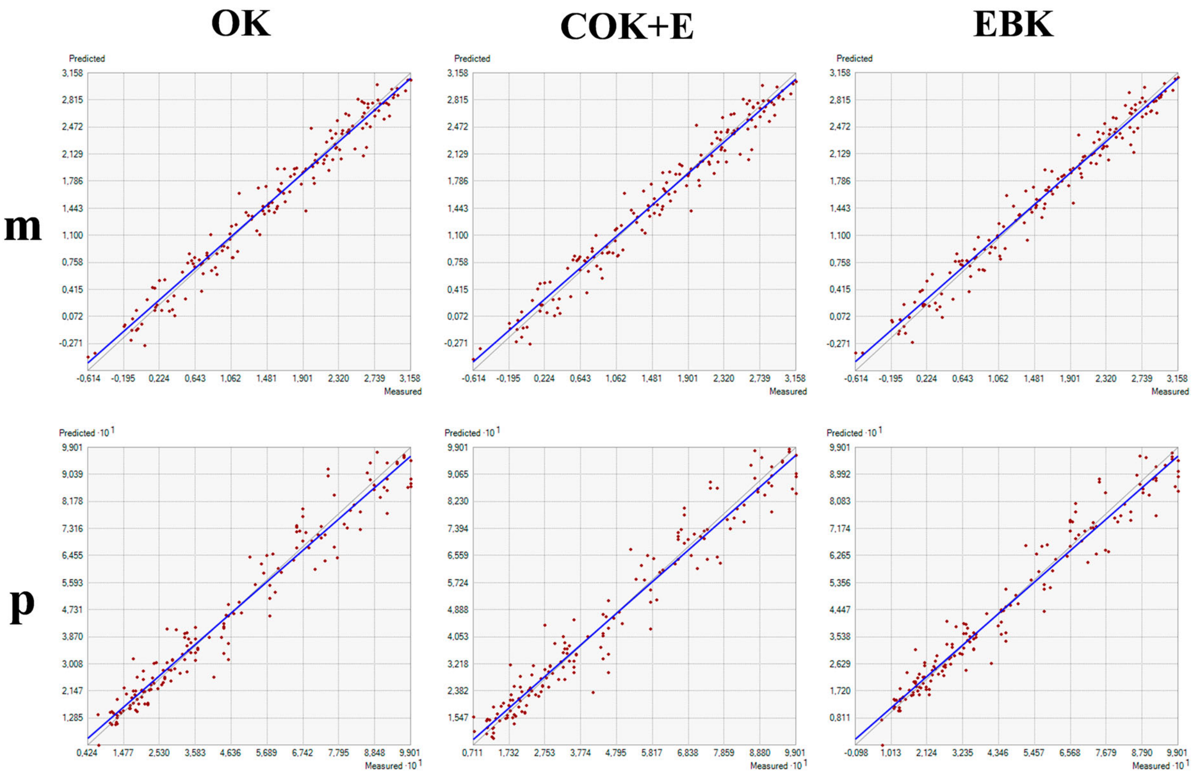

Figure 2. Scatter plots for measured (OX) versus predicted (OY) values of annual ombroxericity slope (m) and *p*-value (*p*) for Ordinary Kriging (OK), Cokriging plus elevation (COK + E) and Empirical Bayesian Kriging (EBK).

Table 3. Parameters of the Empirical Bayesian Kriging carried out.

Parameters	Value
Subset size	90
Overlap factor	1
Number of simulations	1000
Neighbourhood type	Standard Circular
Maximum neighbours	10
Maximum neighbours	2
Radius	0.25

third of the province affected by this increase. Moreover, the area in which the bioclimatic drought has significantly increased penetrates far to the north. The trends show a marked north–south gradient, so that in the northernmost areas ombroxericity would increase at a rate of 0.25 units per year, while in the southernmost areas this rate would be ten times higher. In the northernmost zone of the province, a certain tendency towards invariance or a decrease in ombroxericity can be observed. For July, the line separating negative trends from positive trends (isometric of slope 0) moves south-eastwards. Thus, in the north-westernmost area, as well as in the easternmost part of the province of León, the ombroxericity tends to decrease, while in the south-eastern most area the bioclimatic drought is prone to increase. In August, the trends seem to be reversed. The southern part of the Leonese territory shows decreases in its ombroxericity for the period 1951–2010, while the north, especially the northwest, tends to increase. The changes noted for July and August are not statistically significant.

Figure 3 shows the temporal pattern in two different localities of the province of Leon: Valencia de Don Juan and Ponferrada (see Figure 1) for June, summer and annual. Statistically significant increasing trends are exhibited in the former one for June and summer, but not for the annual study level. For the latter one, a slight upward trend is noted for the three periods under analysis, but it is not statistically significant.

4. Discussion

At annual level, the results obtained are in agreement with those reported by the Intergovernmental Panel on Climate Change (IPCC) in 1998, which noted an increase of about 2°C in the average annual temperatures of the Iberian Peninsula between 1900 and 1990, particularly remarkable from 1950 onwards (IPCC, 1998). IPCC also pointed to a slight decrease in

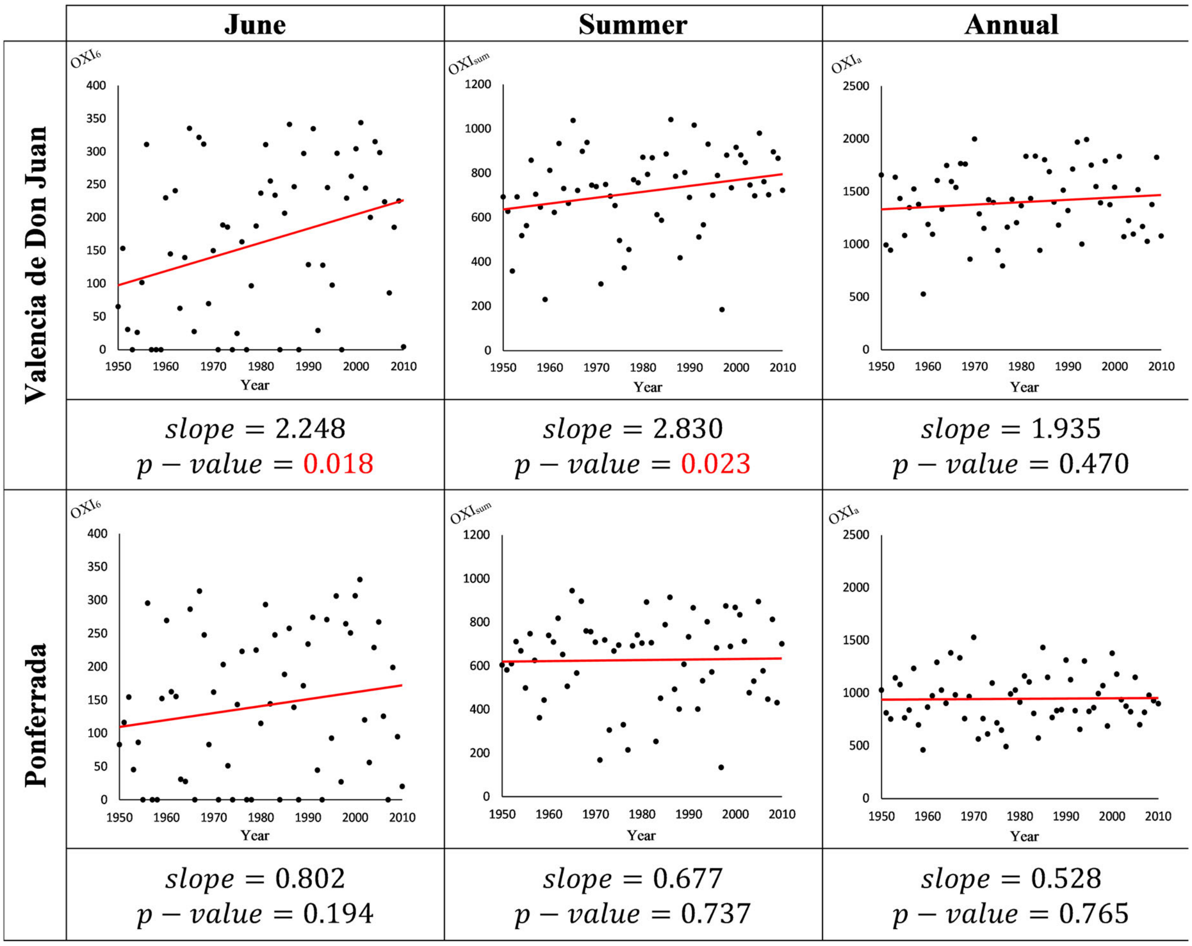

Figure 3. Temporal ombroxericity pattern in two different leonese localities (Valencia de Don Juan and Ponferrada) for the June, summer and annual study periods.

precipitation in the Mediterranean area, although recognising the difficulty of its study due to the large regional and local variations. Thus, the increase in temperatures – coupled with a possible decrease in rainfall – would be responsible for the increase in xericity. However, such increases are not statistically significant according to MKT. It should be noted that the absence of significant trends in drought in the northwest of the Iberian Peninsula has been observed in other studies, and has been attributed to the difficulty in precipitation modelling in this region due to the large variability of orographic factors involved (Lloyd-Hughes & Saunders, 2002). For a rugged territory, a high inter-seasonal and inter-monthly variability is expected. This explains why the significant trends maintained in some localities (e.g. Valencia de Don Juan) for June and summer are lost in the annual computation (Figure 3).

For the summer, the results are also in agreement with the predictions of the IPCC, which pointed to a worsening of droughts in the Iberian Peninsula, especially during the summer and in the Mediterranean region, as a consequence of an increase in average temperatures of up to 4.5°C over the last century (IPCC, 2014). In the spring, this increase in dryness could be related to the decrease in precipitation caused by the positive phase of the North Atlantic Oscillation (NAO), a climatic phenomenon caused by pressure differences between the Azores anticyclone and the Icelandic low pressure area (del Río et al., 2005; Mourato et al., 2010; Ríos-Cornejo et al., 2015a). Regarding autumn, several studies have shown that fall precipitation is increasing both in absolute numbers and in its contribution on the annual precipitation (de Luis et al., 2010; del Río et al., 2011a). However, the observed trends are not statistically significant, probably due to inter-monthly variation. The results observed for spring and autumn seasons coincide with those presented by the IPCC, which point to a decrease in spring precipitation and an increase in autumn precipitation in southern Europe (IPCC, 2014). del Río et al. (2005) detected a change in the typical rainfall regime of Castilla y León, characterised by a decreasing order winter > spring > autumn > summer, towards a winter > autumn > spring > summer order.

Finally, and with regard to the monthly study level, the results observed in March are in line with those found by other authors, who have noted a generalised decrease in spring precipitation from the 1960s onwards, mainly caused by a large drop in March precipitation (del Río et al., 2011a; Mourato et al., 2010; Paredes et al., 2006; Serrano et al., 1999). Paredes et al. (2006) point out that this drop in rainfall is more pronounced towards the centre and west of the Peninsula, particularly in Duerós basin, an area that coincides with that in which increases in March ombroxericity are observed. According to these same authors, the factor responsible for the increase in ombroxericity would be the NAO, whose values have been, at least since 1940, undergoing fluctuations hypothetically caused by the decrease in temperatures in the lower stratosphere, caused in turn by global warming. Then, the positive phase of the NAO coincides in the first weeks of March, displacing the high pressures of the Azores anticyclone, which would bring with itself a period with low precipitation and therefore drier (Paredes et al., 2006). The inverse correlation between NAO value and March precipitation in central and western Spain has also been found by Ríos-Cornejo et al. (2015a). The increasing trend in bioclimatic drought in June cannot be explained by a decrease in precipitation in recent decades, since several studies indicate that there is no such decrease (del Río et al., 2005, 2011a; Serrano et al., 1999). However, other research suggests that a large increase in mean temperature has been occurring in June since 1950, which could be the ultimate cause of the observed trend of increasing ombroxericity (del Río et al., 2011b; González-Hidalgo et al., 2015). This is also in agreement with the predictions of the IPCC (IPCC, 2014). A significant increase in evapotranspiration has also been observed in June, caused by both temperatures and the wind regime, which is becoming more frequent and gustier (Moratiel et al., 2011). Both factors would favour the worsening of xericity conditions, mainly due to the lack of water availability in the soil. All these phenomena discussed for the month of June could be driven by the negative correlation between the mean temperature of that month and the Western Mediterranean Oscillation (WeMO), a regional teleconnection pattern that would push warmer winds to the northwest of the Peninsula (Ríos-Cornejo et al., 2015b). The results for July are partially consistent with what is predicted by the IPCC (IPCC, 2014), which forecasts an increase in temperatures for the summer months, accompanied by a decrease in precipitation in the Mediterranean and an increase in the Temperate zones. Although there are Mediterranean areas of our study area in which the ombroxericity in July seems to tend to decrease (the Bierzo basin, for example), the results do not deviate too much from what is predicted by the leading organisation on climate change. However, in August the trends are the opposite of those expected if we just consider the IPCC predictions, since most of the province suffers a decrease (not statistically significant) in ombroxericity, which can only be explained by an increase in precipitation or a decrease in temperature, scenarios not contemplated for the southern European summer by the aforementioned organisation. However, numerous studies point to an increase in summer precipitation in areas of the globe affected by rising temperatures, given the intensification of 'heavy precipitation' processes (Arnone et al., 2013; Burn et al., 2011; Choi et al., 2017; Christensen & Christensen, 2004; Utsumi et al., 2011). Both Burn et al. (2011) and Arnone et al. (2013) agree that this increase in precipitation would be driven by an increase in rainfall of less than 2 h duration. Utsumi et al. (2011) postulate that this phenomenon would take place through the Clausius–Clapeyron relationship: as surface temperature (especially sea surface temperature) increases, more water is evaporated, which will be available for a precipitation front that will be of short duration, as it is limited by the amount of water that has been able to evaporate. It is consistent to attribute the decrease in ombroxericity observed in August to this cause, since it is the month in which temperatures have increased the most in a statistically significant way in Castilla and León (del Río, 2005). Moreover, in other regions of the world, such as the Korean peninsula, the phenomena occurring in the month of August are already being studied in particular, reaching similar conclusions: increases in temperature leading to higher storm rates and a large increase in precipitation (Choi et al., 2017).

5. Conclusions

In this paper, a model for the xericity trend analysis in a case study region, the province of León, Spain, is proposed based on a bioclimatic approach.

It can be stated that the ombroxericity in the province of León has shown increases in recent decades, mainly during spring and summer, with special mention to the months of March and June, where these increases are statistically significant in a great extent of the study area. Summer is the season with the greatest influence on the trends observed at annual level, which can be contrasted by the direction and position of the isometrics, so that the small areas of decrease in annual ombroxericity can be explained by the non-statistically significant negative trends observed in July and August, as well as in the autumn season. It should also be noted that the northern fringe of the study area, corresponding to the Temperate macrobioclimate zone, generally shows negative trends in summer ombroxericity, either due to decreases in temperature or increases in precipitation, depending on the case, which implies, in any scenario, an intensification of its temperate character.

Further studies will be necessary to clarify the possible change in the rainfall regime of the Iberian Peninsula northwest (spring > autumn instead of autumn > spring), to look for significant trends (positive or negative) in annual drought, and to determinate whether climate change is increasing or decreasing the dryness in the month of August, all of them with aiming to predict what the effects on vegetation will be, using the bioclimatic approach. Also, further studies will be conducted to determine the influence of teleconnection patterns on observed trends.

Software

The Mann-Kendall statistical test was performed using a VBA macro developed by the Department of Computer and Information Science at Linköping University, Sweden (Grimvall et al., 2011). The operational part with the statistics obtained from that test, as well as the cartographic production process, was performed using ArcGIS 10.8.1 software (ESRI, 2019). The Geostatistical Analyst ArcGIS complement was used for geostatistical interpolation.

Disclosure statement

No potential conflict of interest was reported by the author (s).

Data availability statement

The data that support the findings of this study are available from the corresponding author, del Río, S. (sriog@unileon.es), upon reasonable request.

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