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Article

Spatial and Temporal Analysis of Water Resources in the Olive-Growing Areas of Extremadura, Southwestern Spain

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Abstract: The increasing variability of precipitation, higher temperatures and recurring droughts in the semi-arid regions due to climate change are leading to increased aridity, resulting in scarcer water resources for crops. The present study aimed to analyse the spatial distribution of climate variables related to water resources in the olive-growing areas throughout Extremadura, southwestern Spain. To perform this task, three climate variables were used: potential evapotranspiration of the crop, the FAO aridity index and the annual water requirement. Considering data from 58 weather stations located throughout Extremadura and 17 along boundaries with at least 30-year length (within the 1991-2021 period), each variable was computed at each station. After calculating some descriptive statistics, a multivariate geostatistical (regression-kriging) algorithm, incorporating secondary information on elevation and latitude, was used to accurately map each climate variable. Later, temporal trends and their magnitude were analysed using the Mann-Kendall test and the Sen's estimator, respectively. The highest evapotranspiration and water requirements are located in the southern part of the region, which has large areas dedicated to olive cultivation. In the northern part of the region, there is greater spatial variability in evapotranspiration and, consequently, in water requirements for olive groves due to the more rugged topography. Similarly, the olive-growing areas with the highest aridity are also in the south of Extremadura. In most areas of Extremadura, olive cultivation requires appropriate irrigation for optimal productivity. According to evapotranspiration trends, the water requirements will become greater in the future. However, it is not guaranteed that the water supply will be sufficient in olive-growing areas where aridity is higher and water resources are scarce. The results of this study are very important for evaluating water deficit and water resources in vulnerable olive-growing areas throughout Extremadura.

Keywords: Olive; Semi-arid lands; Extremadura; Water requirement

1. Introduction

The reduction in water quantity and quality, along with changing distribution patterns, can have severe impacts on the economy everywhere. Both human and natural-induced phenomena, whether temporary or permanent, can lead to low water availability and consequently water scarcity, which is associated with droughts, aridity and desertification.

Annual precipitation is very likely to decrease in the most area of the southern Europe [1]. Furthermore, the global mean surface temperature is rising. Europe's average temperature has risen

even faster than the global mean, and the southern part of Europe has dried by as much as 20% in the last century [1]. Water balance has been seriously affected by climate and land use change.

The olive tree (*Olea europaea* L.) is one of the most important perennial crops in the Mediterranean region, with Spain being the country with the largest area dedicated to its cultivation. In the southwest of Spain, in the region of Extremadura, olive groves occupy about 270 000 ha [2]. This crop plays a key role in the economy and landscape of a region with significant socioeconomic inequalities, where the olive tree is crucial for rural development and job creation in disadvantaged areas [3]. The cultivation of olive trees has been fundamental for the socioeconomic resilience of rural areas in Extremadura during recent economic crises [4]. Furthermore, traditional olive groves are considered a sustainable agricultural system, playing an essential role at social, economic, and environmental levels [5]. However, water scarcity is one of the main limitations for the growth and productivity of this crop in Extremadura, a region characterised by a Mediterranean climate, which presents particular challenges for agriculture, particularly regarding the availability of water for irrigation.

The study of water requirements of olive trees is crucial for optimising water use and improving irrigation efficiency in this crop. Evapotranspiration is a key parameter for estimating the water requirements of crops. Various studies have estimated olive evapotranspiration in different regions of Spain, with values ranging between 700 and 1100 mm annually, depending on local climatic conditions [6,7]. In the specific case of Extremadura, Orgaz et al. [8] reported olive potential evapotranspiration values ranging between 800 and 900 mm annually, with higher requirements during the summer months. These researchers also noted that under rainfed conditions, the average annual precipitation in the region is not sufficient to meet the water requirements, necessitating supplemental irrigation to maintain productivity of olive groves.

Other climatic indices can be used to characterise water availability in a region and its suitability for olive cultivation. For instance, the FAO aridity index, which considers the ratio between precipitation and evapotranspiration, has been applied in studies throughout Extremadura [9]. The results of these studies have shown that Extremadura has semi-arid climate conditions, with aridity indices indicating a marked water scarcity for much of the year. Moral et al. [9] indicated that in Extremadura, aridity during spring and summer was high (semi-arid) and very high (arid) across almost the entire region. These seasons are critical for the olive tree's vegetative activity, which limits the development and productivity of olive groves under rainfed conditions. Ullah et al. [10] recommended using aridity in indices at regional and local scales to obtain more robust results and formulate better planning, adaptation and mitigation measures related to water resources.

Another widely used index quantifies the crop's water requirements as the difference between the evapotranspiration and the precipitation [11,12]. This difference is crucial for determining the amount of supplementary irrigation needed to maintain the crop in optimal conditions.

In addition to climatic characterisation, the analysis of temporal trends can provide valuable information about the potential effects of climate change on water availability for olive cultivation. Several studies have reported decreasing precipitation trends and increasing evapotranspiration trends in various olive-growing regions of Spain, including Extremadura [13,14]. Net irrigation requirements are expected to increase by 18.5% (70 ± 28 mm per season), reaching up to 140 mm in southern Spain and some areas of Algeria and Morocco [15]. Although the olive tree is a species highly adapted to water scarcity, it performs better with high precipitation or irrigation [16,17]. These changes in climatic conditions could have a significant impact on the sustainability of olive cultivation in the future, as net water requirements could exceed the potential evapotranspiration due to a decrease in precipitation and an even greater impact from droughts and dry periods [15].

The objective of this research is to determine the spatial distribution of climate variables related to water resources in the olive-growing areas throughout Extremadura, using geostatistical techniques, and to analyse their temporal trends. The goal is to develop future water management strategies to improve irrigation efficiency and the sustainability of this crop in the region.

2. Materials and Methods

2.1. Study Area

Extremadura is a region located in the southwest of Spain, bordering Portugal, covering an area of 41 634 km², one of the largest region in Europe. It ranges from 37° 57' to 40° 29' N and from 4° 39' to 7° 33' W. This region has two provinces: Cáceres in the north and Badajoz in the south (Figure 1). Extremadura has vast agricultural and forest areas, and is recognised as an important ecological enclave in Europe. The mean elevation in Extremadura is 425 m a.s.l., ranging from 116 m in the plain of the Guadiana river, near the border between Spain and Portugal, to 2404 m in the north of the region, at the highest elevation in the Sistema Central mountains.

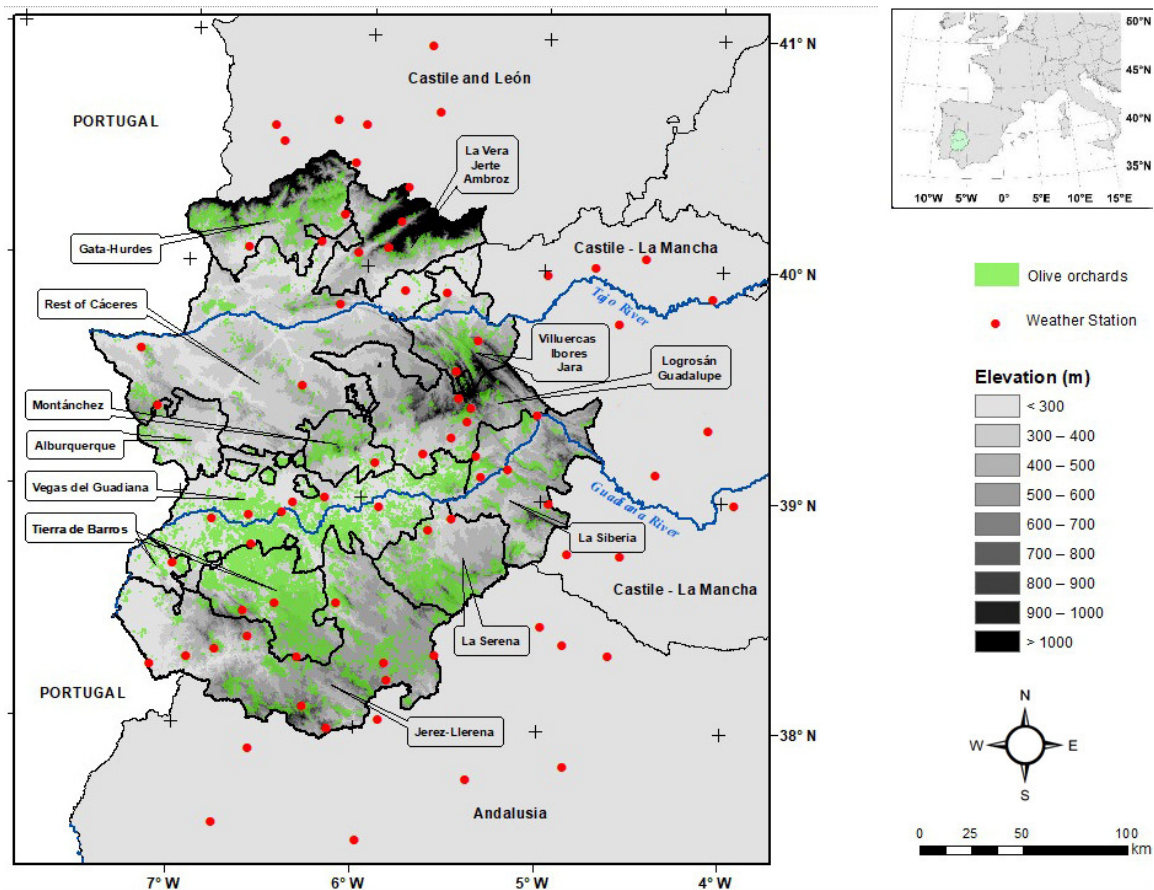


Figure 1. Digital elevation model and olive growing subregions of Extremadura.

Olive cultivation in Extremadura covers an area of 271 404 ha, representing 10.30% of the total olive-growing area in Spain. It is the third autonomous community in terms of area dedicated to olive cultivation and olive oil production, and the second in terms of table olives [2]. The region is divided into 12 olive-growing subregion (OGS), with six in each province (Figure 1). Olive cultivation is mainly located at elevations ranging between 200-600 m a.s.l.

The climate in Extremadura is Mediterranean, influenced by the nearby Atlantic ocean and its inland location. The mean annual temperature is 16.5 °C, but summers are extremely dry and hot, frequently reaching temperatures over 40°C. Winters can be mild and rainy when low-pressure systems dominate or cold and dry when strong anticyclones from northern Europe prevail [18]. During spring and autumn, high climatic variability is usual. Although the mean annual precipitation is 668 mm, it averages less than 600 mm across many zones of the region. Moreover, its interannual variability is very important. Extremadura experiences a dry season, from June to September, and a wet season, from October to May, with 80% of the annual precipitation. The interannual variability of rainfall can be a constraint to olive cultivation, since 50% of the olive-growing area receives less rainfall than is considered adequate for optimum production [19]. The predominant olive cultivation system in the region is extensive and rainfed. However, in recent years, there has been a significant

increase in the area dedicated to irrigated and super-intensive olive cultivation, resulting in a notable rise in average yield.

2.2. Database, Data Treatment and Climate Variables

Daily meteorological observations were obtained at 75 georeferenced weather stations of the Meteorology Agency of the Spanish Government, AEMET [20], located in Extremadura and along boundaries (Figure 1). The initial database contained the UTM geographic coordinates, daily temperature (mean, maximum, and minimum) and rainfall, over the 30-year study period (1991-2021). These data were analysed and mean monthly, seasonal, and annual values of precipitation, air temperature, and evapotranspiration were computed, forming the database for subsequent calculations regarding other climate variables. All daily data set was homogenised and verified according to the quality controls recommended by the World Meteorological Organisation [21] and the Royal Netherlands Meteorological Institute [22]. Missing data were filled in and the homogenisation process was applied using the R package CLIMATOL [23]. The selected weather stations provide adequate spatial coverage and are representative of the climate's behavior and variability in the region. Additionally, using some weather stations along the boundaries of Extremadura can improve estimates in border areas.

Based on the climatic database, three indices were used in this research, calculating the annual averages for the period studied: potential evapotranspiration (PET), FAO aridity index (I_F) and annual water requirement (AWR).

PET for olive cultivation was computed according to the Hargreaves method [24], as recommended by Perez-Rodríguez et al. [25]:

$$PET = 0.0023R_a \left(\frac{T_{\max} + T_{\min}}{2} + 17.8 \right) (T_{\max} + T_{\min})^{0.5} \quad (1)$$

where PET is the daily evapotranspiration, R_a is the extraterrestrial radiation and $T_{\max}$ and $T_{\min}$ are the maximum and minimum daily temperature, respectively.

I_F is the ratio between mean annual precipitation, P_a , and mean potential evapotranspiration, PET_a [26,27]:

$$I_F = \frac{P_a}{PET_a} \quad (2)$$

AWR of a crop is the difference between the PET of the crop and the effective precipitation (the portion of rainfall actually used by the soil), calculated according to the USDA method [28].

2.3. Interpolation Technique and Trend Analysis

While numerous interpolation methods exist for estimating values at unsampled locations, geostatistical algorithms generally outperform deterministic techniques [29,30]. Geostatistics offers a wide range of methods, collectively known as kriging, which are utilised to estimate values at unsampled locations. Various types of kriging involve estimating the value of the studied variable at a specific location based on neighbouring sampling points and a variogram model that considers the distance and degree of variation among all sampling locations. This approach aims to minimise the variance of the estimation error [31].

Univariate geostatistical algorithms, especially ordinary kriging, are commonly employed for estimating climatic variables at unsampled points [32,33]. However, incorporating auxiliary information along with primary data can enhance estimation accuracy through multivariate extensions of kriging methods [29,30]. In this study, the regression kriging algorithm was used. This method is suitable when comprehensive secondary information is available, meaning auxiliary data are accessible throughout the study area [30]. Regression kriging was chosen because it has been shown to produce lower errors when used to estimate climate variables in Extremadura [29].

In regression kriging, predictions are conducted in two distinct stages: first for the trend component and then for the residuals. These two predictions are subsequently combined to derive

the final estimated values. Therefore, the estimation of any climate variable, $Z_{RK}^*(x)$, at a new unsampled point, x , is performed as follows:

$$Z_{RK}^*(x) = m(x) + r(x) \tag{3}$$

Here, $m(x)$, represents the trend fitted using linear regression analysis and $r(x)$ represents the residuals estimated using ordinary kriging algorithm.

In this study, two predictors were used, elevation (h) and latitude (l). Thus,

$$m(x) = a + b\ h(x) + c\ l(x) \tag{4}$$

and,

$$Z_{RK}^*(x) = a + b\ h(x) + c\ l(x) + \sum_{i=1}^n w_i(x) \cdot r(x_i) \tag{5}$$

The difference between the value of the soil property, $Z(x_i)$, and the estimate provided by the trend, $m(x_i)$, is the residual at each sampling point, $r(x_i)$. The weights, $w_i(x)$, are computed by solving the ordinary kriging system of the regression residuals, $r(x_i)$, for the n sample points.

A digital elevation model for Extremadura was used to extract elevation, in raster format (1000 x 1000 resolution). Latitude for the entire region was also utilised in raster format, with the same resolution as the elevation map. Therefore, using point data from weather stations at sampling locations, estimates can be made for any other unsampled location. This approach enables the creation of a continuous surface that covers the entire region, allowing the determination of values for each climate variable (PET, I_F and AWR) at every pixel of the smallest resolution unit. Digital models for each climate variable were generated in raster format with a resolution of 1000 x 1000 m. All operations, including the spatial representation and visualization of the climate variables, were performed using the GIS software ArcGIS v. 10.5. The geostatistical analyses were conducted utilising the Geostatistical Analyst extension within ArcGIS.

The Mann-Kendall test was used to detect temporal trends in the three time series of climate variables, as recommended by the World Meteorological Organization [21]. After computing the statistic of the Mann-Kendall test, increasing trends are indicated by positive values, while decreasing trends are indicated by negative values. In this study, the 5% significance level was used, meaning the null hypothesis of no trend was rejected when the absolute value of the statistic was higher than 1.96.

With the aim of identifying the gradients and their directions, the Sen’s non-parametric method was used [34]. Thus, the MAKESENS 1.0 was utilised. It is a computer model introduced by Salmi et al. [35], which was built using Microsoft Excel 97 and macros coded with the Microsoft Visual Basic language.

3. Results and Discussion

3.1. Descriptive ANALYSIS of data and Spatial Distribution of the Climate Variables

Some descriptive statistics were used to characterise the data distribution (Table 1). The mean and median values for PET were similar. Moreover, the skewness value was low; in consequence, all these values are indicative of PET data coming from a normal distribution. However, more differences between the median and the mean values were apparent for the AWR and I_F . Additionally, the skewness values were higher. These statistics suggest that AWR and I_F data fitted a lognormal distribution.

Table 1. Descriptive statistics of the climate variables from 75 weather stations in Extremadura and along its boundaries.

Variable	Mean	Median	Standard deviation	Minimum	Maximum	Coefficient of variation (%)	Skewness
Potential evapotranspiration (PET)	821.62	828.89	56.32	653.75	902.06	6.85	-0.89
FAO aridity index (I_F)	-0.76	0.66	0.30	0.47	1.88	39.47	2.01

Annual water requirement (AWR)	-228.01	-297.73	225.71	-475.02	519.06	98.99	1.71
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The distributions of PET and AWR were shifted to higher values, as indicated by median values being higher than the mean values. Conversely, the distribution of I_F was shifted to lower values, with the mean value being higher than the median value. This is coherent because higher PET values lead to increased water requirements and, consequently, greater aridity, meaning lower I_F values should predominate. Furthermore, the wide difference between minimum and maximum values and the high coefficients of variation for all climate variables denote significant climatic spatial variability in Extremadura.

Despite the previous description of the three climate variables in Extremadura, based on point values at the weather stations, it is evident that spatial variability can exist within all OGS. Therefore, a more accurate analysis is necessary to properly understand the patterns of each variable considered in this study. Consequently, the spatial representation of each climate variable is an essential tool for precisely visualising the climatic characteristics in Extremadura.

The spatial patterns of PET, AWR and I_F in Extremadura are shown in Figure 2. Tables 2, 3 and 4 show some statistics for each OGS, considering the three climatic variables.

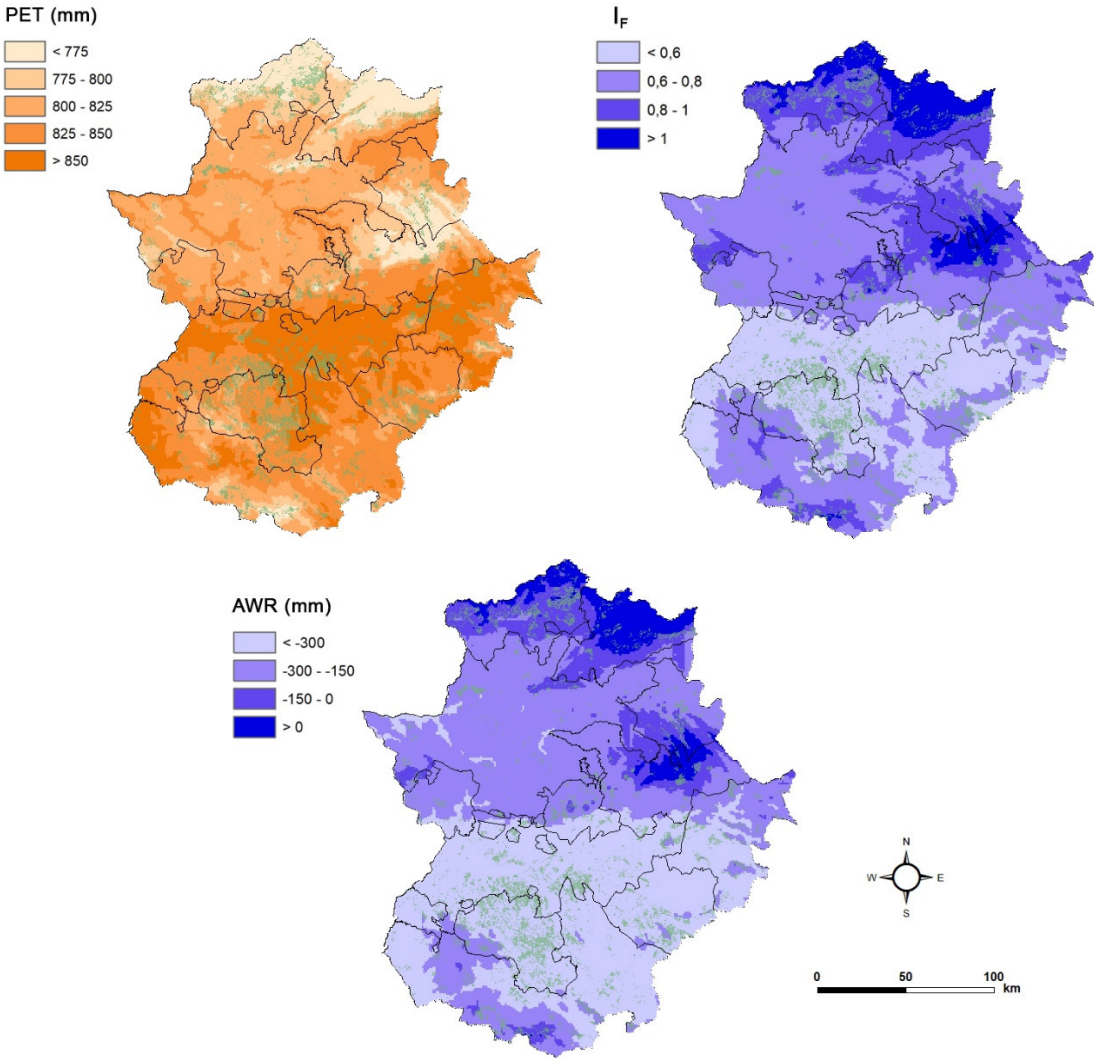


Figure 2. Spatial distribution of the potential evapotranspiration (PET), the FAO aridity index (I_F) and the annual water requirement (AWR) in Extremadura considering the baseline climate, 1991-2021. Olive-growing subregions and olive areas (in green) are also indicated.

Table 2. Descriptive statistics of the potential evapotranspiration in each Extremaduran olive-growing subregion.

Natural Region	Potential evapotranspiration (PET)				
	Minimum	Maximum	Mean	SD	CV (%)
Gata-Hurdes	624.69	826.17	768.84	39.01	5.07
La Vera-Jerte-Ambroz	497.62	856.37	753.33	73.32	9.73
Ibores	694.52	845.89	793.59	31.39	3.95
Logrosán-Guadalupe	660.92	868.87	809.80	34.06	4.21
Montánchez	754.91	865.73	829.08	19.68	2.37
Resto de Cáceres	731.44	862.48	814.23	13.19	1.62
Alburquerque	784.89	873.53	825.15	16.53	2.00
La Siberia	778.48	882.11	847.28	18.03	2.13
La Serena	784.34	871.36	840.90	12.61	1.49
Vegas del Gadiana	799.09	889.56	854.14	14.59	1.71
Tierra de Barros	775.24	870.14	834.57	15.33	1.84
Jerez-Llerena	733.83	886.29	832.74	21.29	2.56

Table 3. Descriptive statistics of the annual water requirements in each Extremaduran olive-growing subregion.

Natural Region	Annual water requirement (AWR)				
	Minimum	Maximum	Mean	SD	CV (%)
Gata-Hurdes	-247.89	432.23	-60.64	112.71	185.86
La Vera-Jerte-Ambroz	-217.03	984.74	135.36	286.94	211.98
Ibores	-298.11	279.45	-145.49	101.39	69.68
Logrosán-Guadalupe	-364.63	396.48	-147.96	130.88	88.46
Montánchez	-405.37	-11.21	-258.79	79.27	30.63
Resto de Cáceres	-355.48	137.70	-221.89	53.82	24.26
Alburquerque	-389.61	-110.25	-276.81	58.31	21.06
La Siberia	-437.22	-86.48	-301.39	67.54	22.41
La Serena	-477.12	-216.27	-381.80	44.12	11.56
Vegas del Gadiana	-468.58	-219.28	-392.16	40.11	10.23
Tierra de Barros	-469.00	-147.15	-359.74	51.01	14.18
Jerez-Llerena	-479.71	17.64	-317.08	78.10	24.63

Table 4. Descriptive statistics of the FAO aridity index in each Extremaduran olive-growing subregion.

Natural Region	FAO aridity index (I _r)				
	Minimum	Maximum	Mean	SD	CV (%)
Gata-Hurdes	0.70	1.61	0.95	0.15	15.79
La Vera-Jerte-Ambroz	0.75	2.32	1.23	0.39	31.71
Ibores	0.64	1.42	0.85	0.13	15.29
Logrosán-Guadalupe	0.58	1.58	0.86	0.17	19.78
Montánchez	0.54	1.05	0.72	0.10	13.89
Resto de Cáceres	0.57	1.21	0.64	0.07	10.94
Alburquerque	0.55	0.91	0.69	0.07	10.14
La Siberia	0.49	0.94	0.67	0.09	13.43
La Serena	0.44	0.78	0.57	0.06	10.53
Vegas del Gadiana	0.46	0.77	0.55	0.05	9.09
Tierra de Barros	0.46	0.86	0.59	0.06	10.17
Jerez-Llerena	0.45	1.08	0.65	0.09	13.85

If the mean PET is considered, the highest values were found in the southern part of Extremadura, in six OGS in the province of Badajoz (Alburquerque, Vegas del Gadiana, Tierra de Barros, La Siberia, La Serena, Jerez-Llerena) and one in the province of Cáceres (Montánchez). These mean PET range from 825.15 mm in Alburquerque to 854.14 mm in Vegas del Gadiana. Conversely, the lowest mean PET values were found in the northern part of the region, where elevation is higher due to the existence of some mountain systems. In these OGS, mean PET values range from 753.33

mm in LaVera-Jerte-Ambroz to 814.23 mm in the center of Cáceres. Moreover, variability is higher in the northern OGS, as expected, due to significant differences in elevation.

When the AWR was considered, only one OGS (La Vera-Jerte-Ambroz) showed a positive value, indicating that irrigation is not necessary there. In all other OGS, there is an annual water deficit, ranging from 60.64 mm to 392.16 mm, which is more pronounced in the southern OGS of Extremadura (Table 3). As with PET, variability was also higher for AWR in the northern OGS due to the more significant topographical contrast.

According to the I_F , there are three categories in Extremadura. Dry sub-humid ($0.50 \leq I_F < 0.65$) characteristics, where I_F ranges from 0.55 to 0.64, are predominant (Table 4). In these OGS, precipitation is well below the values of PET, and consequently, the water requirements through irrigation are more pronounced. Logically, these OGS correspond to those showing higher AWR values. Conversely, the OGS in northern Extremadura, in the province of Cáceres, have the highest mean I_F values, ranging between 0.85 and 1.23, falling into the more humid category. In these OGS, there is a lower water requirement through irrigation, with the extreme case of La Vera-Jerte-Ambroz, where precipitation even exceeds the demand from PET. Three other OGS, located in the central part of the region, fall into a medium I_F category, with values between 0.67 and 0.72, but they also require irrigation to meet the PET demand.

The spatial distribution of PET, AWR and I_F in the Extremaduran OGS was properly provided by maps of kriged estimates and, additionally, these surfaces were very accurate. When the ratio between the root mean square error and the mean value of each climate variable was computed, values lower than 3.5% were obtained for all variables. This fact denotes that all maps characterised very closely the real spatial patterns of each climate variable.

The climate variations observed in this research according to the three indices suggest that olive cultivation management, particularly regarding water management, needs to be approached differently in each OGS. This spatial variability could become even more significant in the near future, as a decrease in water resources of more than 50% is expected in approximately 90% of Extremadura [36], along with a significant increase in aridity conditions [9]. The productivity of olive cultivation will be significantly reduced under these new climatic conditions, to the point where it may no longer be viable to grow olives under rainfed conditions in many OGS where it is currently feasible. Additionally, the optimal areas for olive cultivation could shift to OGS with higher elevation and greater availability of water resources.

3.2. Trend Analysis

After computing the statistic of the Mann-Kendall test and the magnitude of trends approximated by the Sen's estimator, the results showed that only PET at some locations exhibited significant increasing trends.

Figure 3 shows the weather stations, in Extremadura and around the region, where trends were significant at the 0.05 level. Most of these locations in Extremadura are in the western part of the region, with all trends being positive, indicating that higher PET values are expected. Only one location in the north and at a site with more humid climate, according to the I_F , has a significant trend. In contrast, in the south locations, where more arid conditions prevail, PET is the highest in the region. Consequently, with an increase of PET in these areas, the water availability decreases, leading to a drier climate, which impact on water requirements of olive trees.

With respect to the rate of increasing trend of PET at those locations in Extremadura in which the trends were significant, it ranges from 0.96 mm to 2.47 mm. Particularly, in the two northern locations, their values were 1.01 mm and 1.70 mm, and in the four more to the south, their values were higher than 2 mm. This suggests that the southwestern area of Extremadura, and the existing OGS there, can be more seriously affected by an increasing PET. Figure 3, where the spatial pattern of the magnitude of trend is visualised, shows this fact more easily. Using the ordinary kriging algorithm, the kriged map shows how the north and east of Extremadura constitute the zones of the region in which the trends have a lower increasing rate, lower than 0.5 mm. Even in the easternmost

area of the region, there is a large zone with negative trends, meaning that the PET decreases. In contrast, the western area has the higher increasing rate, with values higher than 1 mm.

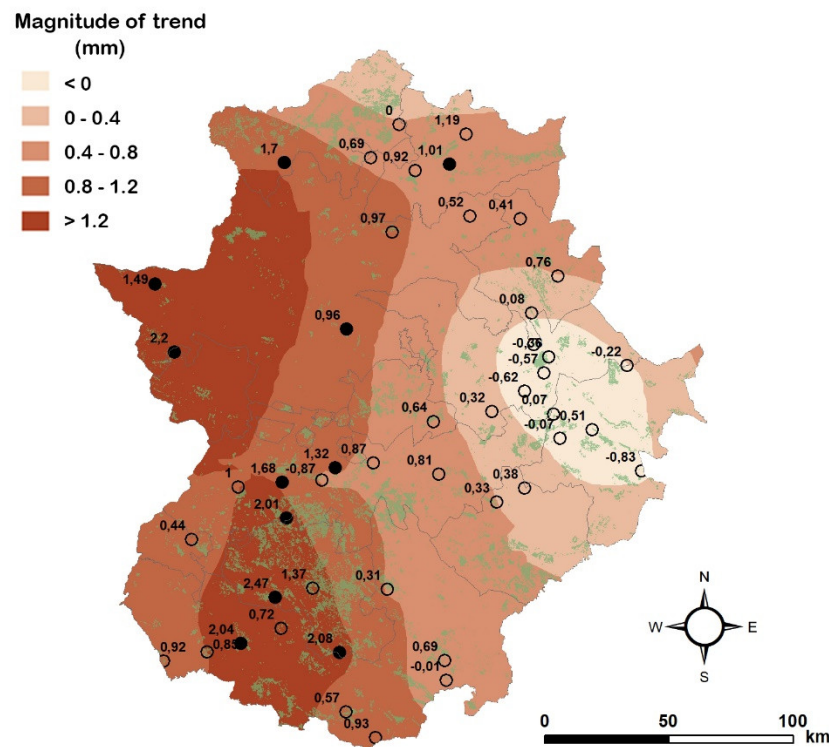


Figure 3. Spatial distribution of the magnitude of trend of the potential evapotranspiration in Extremadura. Black points show the locations in which significant trends at the 5% level were found.

As drier regions are more sensitive to the availability of water resources [37], changes in PET can alter the intensity of desertification. This can more seriously affect the OGS in the southwestern of Extremadura, where PET is higher and AWR is lower. In these OGS, olive groves require a large amount of water, which will be larger in the near future, but may not be available. Moreover, aridity in Extremadura, and particularly in the south of the region, will progressively increase during this century [38]. This makes the region more vulnerable to climate change, shifting the OGS to drier conditions, more intensively in the south. These results are consistent with those obtained by Lozano-Parra and Sánchez-Martín [36], who indicated that water resources in Extremadura could decrease by up to 55% in agricultural areas.

4. Conclusions

The availability of water resources for olive cultivation, both under rainfed and irrigated conditions, is essential for achieving good productivity and, consequently, optimal profitability. Therefore, high-resolution knowledge of the spatial distribution of the main climatic variables that influence water availability is of great importance for evaluating this resource at both regional and local scales.

The present study analyses these spatial variations in Extremadura using PET, IF and AWR as climatic indices, considering the OGS throughout the region. Moreover, the temporal trends were also studied to analyse the expected evolution. Although significant increasing trends were observed only in PET at some locations, the results of this study are crucial for evaluating water resources. This information can help predict practical measures to control more vulnerable areas, where olive cultivation could be seriously affected in the near future due to compromised water supply.

In most areas of Extremadura, the AWR is negative, indicating that olive cultivation requires appropriate irrigation for optimal productivity. According to PET trends, the AWR will become more negative in the future, necessitating even more water. However, it is not guaranteed that the water

supply will be sufficient in areas where the climate is characterised by aridity and water resources are highly scarce and under intense competition, primarily for non-agricultural uses.

The majority of olive cultivation in Extremadura is rainfed, and it is expected to face greater stress in the future, becoming unfeasible in many areas of the region. This situation will have significant consequences, including land abandonment and landscape deterioration, leading to a loss of soil and water conservation measures and increased erosion. Additionally, the social consequences of abandoning traditional olive groves could be enormous.

Olive evapotranspiration and irrigation requirements strongly depend on the type of cultivation (traditional, intensive, or super-intensive), that is, tree density and fraction of ground cover. Consequently, crop water requirements could increase even more if super-intensive olive groves continue to expand. Due to potentially high water requirements and limited water availability, regulated deficit irrigation will likely become a common practice in most areas, as it is currently developing. However, achieving water savings and high yields requires careful irrigation scheduling

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