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Exploring the Impact of Climate Change on Water Resources for Vegetation Covers in Extremadura (Spain)

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Abstract: Mediterranean areas will likely undergo climate shifts in the near future that modify the water resources for vegetation. However, in some regions of southwestern Spain, such as Extremadura, the impact of different future scenarios on the water resources for vegetation has not been studied extensively. This study focused on the quantification and spatial distribution of water resources for vegetation covers in Extremadura and analyzed the impact of future climate change scenarios on those water resources. For this, five downscaled global climate models from Coupled Model Intercomparison Project phase 6 (CMIP6) were used in four future periods (from 2021 to 2100) following two Shared Socioeconomic Pathways (SSP-2.45 and SSP-5.85). These projections were compared with a historical baseline period (1970–2000) to obtain the variation of water resources. The results showed decreases in the water resources for all the scenarios and periods analyzed compared to those observed in the historical baseline period. The smallest decreases were noted over 2041–2060 for SSP2-4.5, with almost 74% of the region decreasing between 15 and 18% (with an average of 16.4%). The greatest decreases were over 2081–2100 for SSP5-8.5, in which 90% of the region displayed water resource declines of greater than 50%. In this last situation, the three more widespread vegetation covers (agrosilvopastoral systems of dehesas, grasslands, and crops) underwent similar declines of around 55% of their water resources (from ≈203 to ≈93 mm), while the fourth widely spread vegetation cover, forests, declined by 49% (from ≈261 to ≈133 mm). If any of these future projections occur, the decline in water resources could modify the forest composition and structure of these water-dependent ecosystems, compromising their maintenance and ecological, cultural, and economic functions.

Keywords: water; vegetation; climate; geography; Extremadura

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1. Introduction

Water resources are essential to biophysical processes and human activities [1]. However, the availability of water resources is increasingly threatened by climate change, which could compromise ecosystem maintenance and human development [2]. Climate change modifies the flows and patterns of atmospheric and hydrological processes, therefore influencing the spatiotemporal distribution of water resources globally [3–5]. In recent decades, the Mediterranean region has experienced significant modifications in climate patterns characterized by rising temperatures, variations in precipitation, and the increased frequency of extreme weather events [6,7]. These changes have deep implications for water resource management, posing challenges to both environmental sustainability and socio-economic development. Understanding the modifications triggered by climate change on water resources is important to develop effective strategies to mitigate their impacts on ecosystems and human societies.

In Mediterranean areas with semiarid climates, water resources play a crucial role, especially in southern regions such as Extremadura, where potential evapotranspiration rates typically double precipitations [8,9]. As a result, water resources show strong seasonal fluctuation, and their availability is quite unforeseeable, so water management remains a persistent challenge.

In Extremadura, vegetation covers directly depend on the water availability. This is the case of agrosilvopastoral systems called dehesas, the most widely spread ecosystems in this region and in the southwest of the Iberian Peninsula. This water-limited environment can be defined as a seminatural and multipurpose ecosystem consisting of grazed grasslands with scattered trees (mainly holm and cork oaks) resulting from tree clearing. According to the European Union, it is a high-nature-value farming and forestry system and has very significant importance in the region from an economic, cultural, and environmental standpoint [10,11]. Nevertheless, in the last decades it has experienced serious sustainability issues related to tree decline and renewal [12], and a significant increment in water ponds to face the increased livestock consumption and the dry season [13]. Extremadura presents other widely extended vegetation covers with great economic, cultural, and environmental significance, such as grasslands or forests. These water-dependent ecosystems directly rely on precipitation, so climate variability will determine their maintenance and functioning. Similarly, there also are noticeable economic sectors that are dependent on hydrological resources, such as agriculture and livestock [14]. However, croplands rely heavily on precipitation and irrigation to support their production, while extensive livestock depends directly on the capability of the environment to produce biomass and, therefore, on climate variability.

The complex interaction between climate and vegetation in this Mediterranean region has been tackled by using different approaches and procedures. Field studies have improved the knowledge on the responses of vegetation to climate variations, including the relationships between soil moisture and herbaceous plant productivity, shifts in growth patterns, and phenological events [15–17]. Remote sensing techniques have also advanced the monitoring of vegetation cover on large spatial scales, allowing one to observe that the response to drought and the variability of water budget change according to the vegetation communities [18,19]. Modeling the approaches has allowed progress in different subjects such as assessing the effects of the variations of hydrological processes on vegetation productivity, phenology, and species distribution [20–22]. However, despite the aforementioned, the impact of different future scenarios on water resources for the vegetation covers in this specific region of southwestern Spain remains still little studied.

The climate projections from global climate models (GCMs) and regional climate models (RCMs) provide data for assessing the effect of climate change on different spatial scales [2]. These projections consider a set of future scenarios comprising land use and emissions as required for the future Shared Socioeconomic Pathways (SSPs) which were presented by the Intergovernmental Panel on Climate Change (IPCC) in their Sixth Assessment Report (CMIP6) [23]. Climate change projections are important, for example, to estimate the changes in the quantity and distribution of future water resources compared to the current ones. This is especially significant in Mediterranean regions with dry seasons and unpredictable precipitation such as Extremadura, where the spatial analysis of future climate scenarios could support the management of their water resources. Some studies, such as the one carried out by Moral et al. [24], have analyzed the impact of climate change on the viticulture sector, concluding that a significant proportion of the total area of Extremadura will be too hot for this activity. However, despite their significant advancements, studies focusing on the impact of climate change on water resources for vegetation covers in this particular region are still very scarce.

It seems clear that Mediterranean ecosystems will undergo climate shifts in the near future, characterized by reduced precipitation and increased temperatures. These recognized changes require a thorough examination by using several approaches, one of them particularly focusing on the quantification and spatial distribution of water resources for vegetation covers. Thus, to provide the relevant information on this topic in the Spanish region of Extremadura, the following questions are addressed: (I) How are the current water resources quantitatively and spatially distributed? (II) How could water resources change quantitatively and spatially under different climate change scenarios? (III) How could water resources change in the more widely spread vegetation covers in Extremadura?

2. Study Area

The Spanish region of Extremadura has a surface area of approximately 41,600 km^2 and elevations ranging from 2400 to 150 m (Figure 1), with a mean elevation of 430 m (the standard deviation is 188 m). Its population slightly surpasses one million inhabitants and is distributed in small cities and scattered villages.

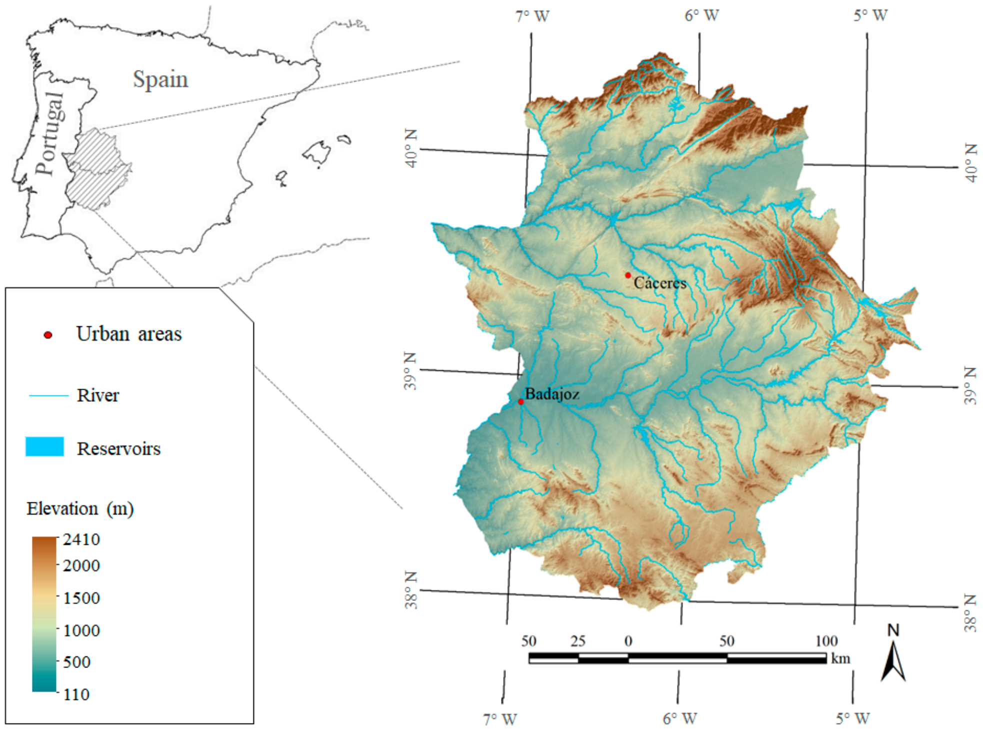

Figure 1. Location of the Spanish region of Extremadura.

The geology is mainly constituted by Precambrian schists, slates, greywackes, and Hercynian-age granitic intrusions. The geomorphology is diverse. The prevailing landscape lies upon an ancient erosion surface that exhibits gentle undulations with mountain areas in the north and south. The lower areas comprise alluvial plains and steep slopes in river channels.

The soils are typically shallow with a thickness generally of less than 50 cm [15]. Their textures range from silty to sandy, they usually are poor in nutrients and organic matter, and have a high bulk density. According to the FAO classification [25], the main soil types include Cambisols, Luvisols, and Leptosols.

The dominant climate is the Mediterranean with variations from subhumid to semi-arid temperate, and it presents modifications derived from altitude.

The vegetation usually displays three layers—trees, shrubs, and grasses—with different combinations and densities. In the tree layer are predominant species like holm oak (*Quercus ilex*), cork oak (*Quercus suber*), and Pyrenean oak (*Quercus pyrenaica*). To facilitate herbaceous plant growth for livestock grazing, the shrub layer is frequently removed by ranchers. Finally, the herbaceous layer is usually composed of annual grasses (peaking in spring with a secondary maximum in autumn and a non-vegetative phase during summer) and perennial grasses.

3. Materials and Methods

3.1. Vegetation Covers of Extremadura

The spatial distribution of vegetation covers in Extremadura was obtained from the Spanish Forestry Map [26], which constitutes the most basic and up-to-date official forest cartography of Spain. It has been developed at a 1:25,000 scale via a three-phase process: photointerpretation of digital orthophotography, field verifications, and quality controls. This product comprehensively depicts the spatial distribution of Spanish vegetation covers. It provides detailed, continuous, and consistent information for the whole country in a thorough vegetation database, including variables such as vegetation structure and land use, vegetation density rate, and the mapped main tree species. From this database, the ten vegetation covers with a greater surface area in Extremadura were identified and selected (Figure 2). It was justified because the surface area occupied by all of these together was greater than 90% of all the regional territory (Table 1).

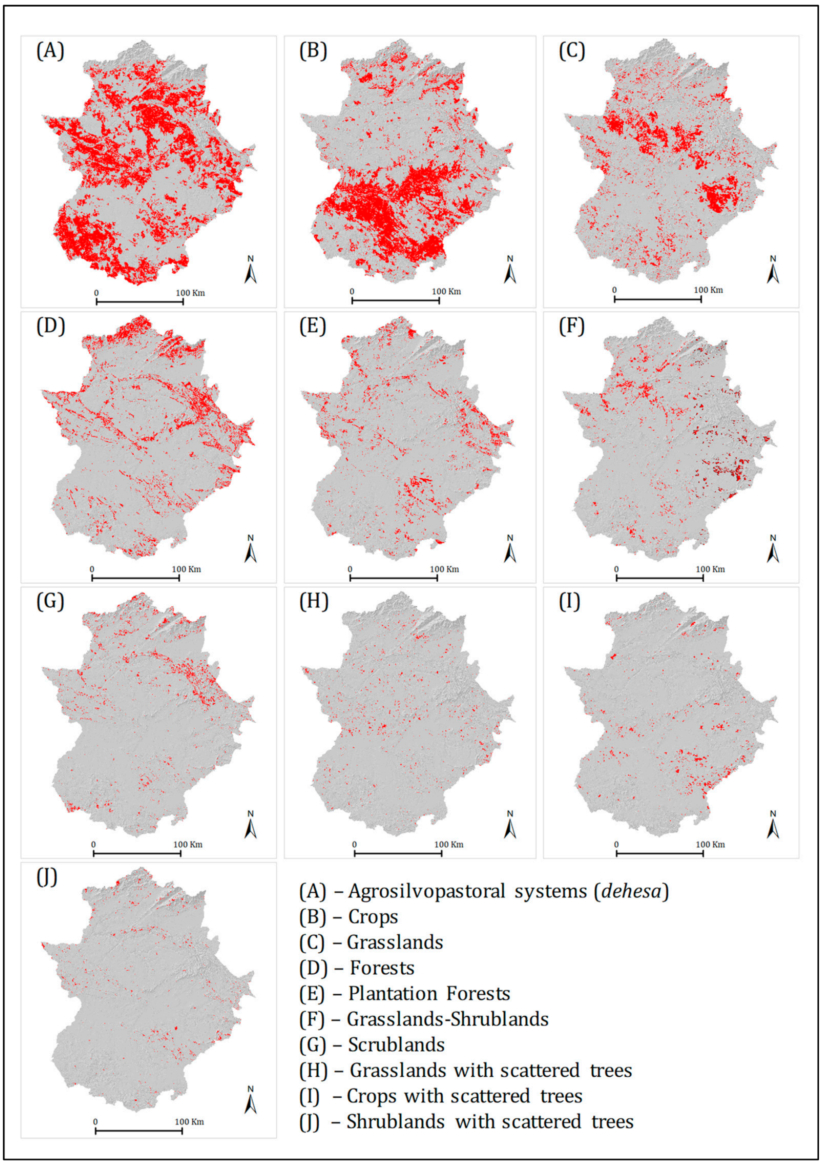

Figure 2. Spatial distribution of the more widely spread vegetation covers in Extremadura (according to DGBBD [26]) Red color depicts the spatial distribution of vegetation cover.

Table 1. Topographical properties of vegetation covers in Extremadura. The surface area percentage was calculated regarding total extension of Extremadura. A = Agrosilvopastoral systems (dehesa); B = Crops; C = Grasslands; D = Forests; E = Plantation Forests; F = Grasslands–Shrublands; G = Scrublands; H = Grassland with scattered trees; I = Crops with scattered trees; J = Shrublands with scattered trees.

Vegetation Cover	Surface		Elevation (m)				Slope (°)			
	km^2	%	Max	Min	Mean	SD	Max	Min	Mean	SD
A	13,233	31.8	1448.0	114.9	399.8	119.4	52.7	0.0	5.1	4.1
B	9803	23.5	1362.0	87.6	388.9	142.2	56.5	0.0	2.9	3.4
C	4187	10.1	2248.9	116.0	396.3	113.8	53.4	0.0	3.4	2.8
D	4020	9.65	1744.4	74.7	581.4	244.0	62.1	0.0	13.6	7.7
E	2100	5.04	2005.8	114.5	497.2	183.3	45.5	0.0	8.8	6.2
F	1465	3.52	2167.1	116.1	399.1	166.6	54.9	0.0	6.6	4.9
G	1211	2.91	2384.1	114.0	570.9	332.8	61.2	0.0	11.3	7.2
H	567	1.36	1021.5	115.3	380.5	105.0	43.1	0.0	3.3	2.8
I	554	1.33	1172.6	150.3	410.0	129.9	47.4	0.0	3.9	4.0
J	437	1.05	1801.3	114.0	537.5	237.7	52.3	0.0	11.2	6.8

The most widely spread vegetation cover in Extremadura is the agrosilvopastoral systems called dehesas, occupying almost a third of the regional surface area (Table 1, A). They are located throughout the region except in areas higher than 1500 m. The second-greatest surface area is occupied by crops and includes areas of intensive and extensive crops (Table 1, B). They are mostly found in flat areas, as indicated by their low mean slopes. Grasslands and forests occupy the third- and fourth-greatest surface areas, respectively (Table 1, C and D). The first ones were defined as communities of annual and perennial herbaceous plants extensively grazed by livestock, so they are crucial for the grazing economy; however, their growth is very dependent on climate variability. Forests were defined as grouped trees with a natural or repopulated origin. Their use is only for forestry, and they are located in areas with high slopes and complex topography, such as mountain ranges. Forest plantations are similar to the previous ones but, in this case, their origin is artificial (Table 1, E). To be considered a natural forest, the elements revealing an artificial origin (boundaries, frames, etc.) must appear dissolved. The shrubby areas are occupied by two vegetation covers, grassland–shrublands and scrublands (Table 1, F and G, respectively). The first ones consist of a mix of shrubs with herbaceous plants, while the second ones are dominated by bushes and are located in steeper areas. The last three vegetation covers (Table 1, H, I, and J) occupy just over 3% of the regional surface area and come from ancient dehesa uses. More detailed and comprehensive information about these vegetation covers can be found in DGBBD [26].

3.2. Current and Future Climate Scenarios

To define water resources on a regional scale in present and future periods, different temporal intervals were used. The first one was called the historical base period and was used as a baseline to define the current climate and hydrological context. It was obtained from Fick and Hijmans [27], who used historical climate data based on the instrumental observations from satellites and thousands of meteorological stations spread throughout the world. This period included monthly climate data of minimum, mean, and maximum temperature, and precipitation, aggregated across a target temporal range of 1970–2000. These variables were interpolated to generate a spatially continuous grid on a global scale with a resolution of 1 km^2. The interpolation method was based on a smoothing spline algorithm that operates by considering covariance analysis and the spatial distributions of standard error. This method can be viewed as a generalization of standard multivariate linear regression, where the parametric model is replaced by a smoothed non-parametric function [28,29].

Future periods were averaged over 20-year intervals (2021–2040, 2041–2060, 2061–2080, 2081–2100) and were generated for monthly values of minimum and maximum temperature and precipitation, on a spatially continuous grid on a global scale with a resolution of 1 km^2. Each period was individually obtained from different downscaled Global Climate Models (GCMs). As each GCM gives different results, five were selected: ACCESS-CM2, CMCC-ESM2, FIO-ESM-2-0, GISS-E2-1-G, and HadGEM3-GC31-LL. These GMCs were part of the CMIP6 downscaled future climate projection [23]. The selected future periods were also generated considering two emission scenarios or Shared Socio-economic Pathways (SSPs): the SSP2-4.5 and SSP5-8.5 scenarios [30]. The first scenario constitutes a midpoint among others and exhibits a trajectory where social, economic, and technological trends describe the minimal deviation from the established historical patterns. This world would show intermediate Greenhouse Gas (GHG) emissions, CO_2 emissions around the current levels until 2050, and then a fall but not reaching net zero until 2100. In the second scenario, the world's development would be fueled by fossil fuels, i.e., there would be very high GHG emissions, with CO_2 emissions tripling by 2075. This world would become more confident in competitive markets, innovation, and participatory societies to achieve fast technological advances and human progress as the way to sustainable development [2,31].

3.3. Determining Water Resources

Water resources of the region of Extremadura were defined by the following expression:

$$\mathrm{WR} = \mathrm{P} - \mathrm{ETa}$$

where WR denotes the water resources (mm) that would hypothetically be available for vegetation; P depicts the precipitation (mm); and ETa constitutes the actual evapotranspiration (mm). These variables were annually generated for each grid cell using a resolution of 1 km^2.

Actual evapotranspiration was annually calculated using the Turc [32] method. This widely used procedure has successfully been tested and validated to estimate the water balances in different situations [33–35]. Its simplicity and minimal data requirements make it valuable in calculating the actual evapotranspiration on an annual basis in locations where detailed meteorological data are scarce or in data-limited scenarios [36–39]. More detailed information about the application of this procedure can be found in Lozano-Parra et al. [40]. All spatial analyses were tackled by applying map algebra using ArcGIS 10.8.1.

Once hydroclimate variables were defined for the historical base period and future scenarios, the changes between them were calculated to obtain their variations.

4. Results

4.1. Current Water Resources and Hydroclimate Conditions

The historical baseline period showed water resources averaging at 213.2 mm in the region (the standard deviation was 79.4 mm) (Figure 3). Their spatial distribution presented relative homogeneity and variations partially related to the orography (a simple correlation analysis revealed that elevation could explain 54.8% of the variance observed in water resources). Of the regional surface area, 93.7% presented water resources lower than 300 mm, and only areas with altitudes higher than 500 m (≈75% of the territory is below this elevation) were prone to show resources greater than 400 mm. The vegetation covers with the greatest water resources were forests, with 260.9 ± 118.5 mm (mean ± 1 standard deviation), while dehesas, the more widespread vegetation cover, recorded 202.6 ± 43.0 mm (Figure 4).

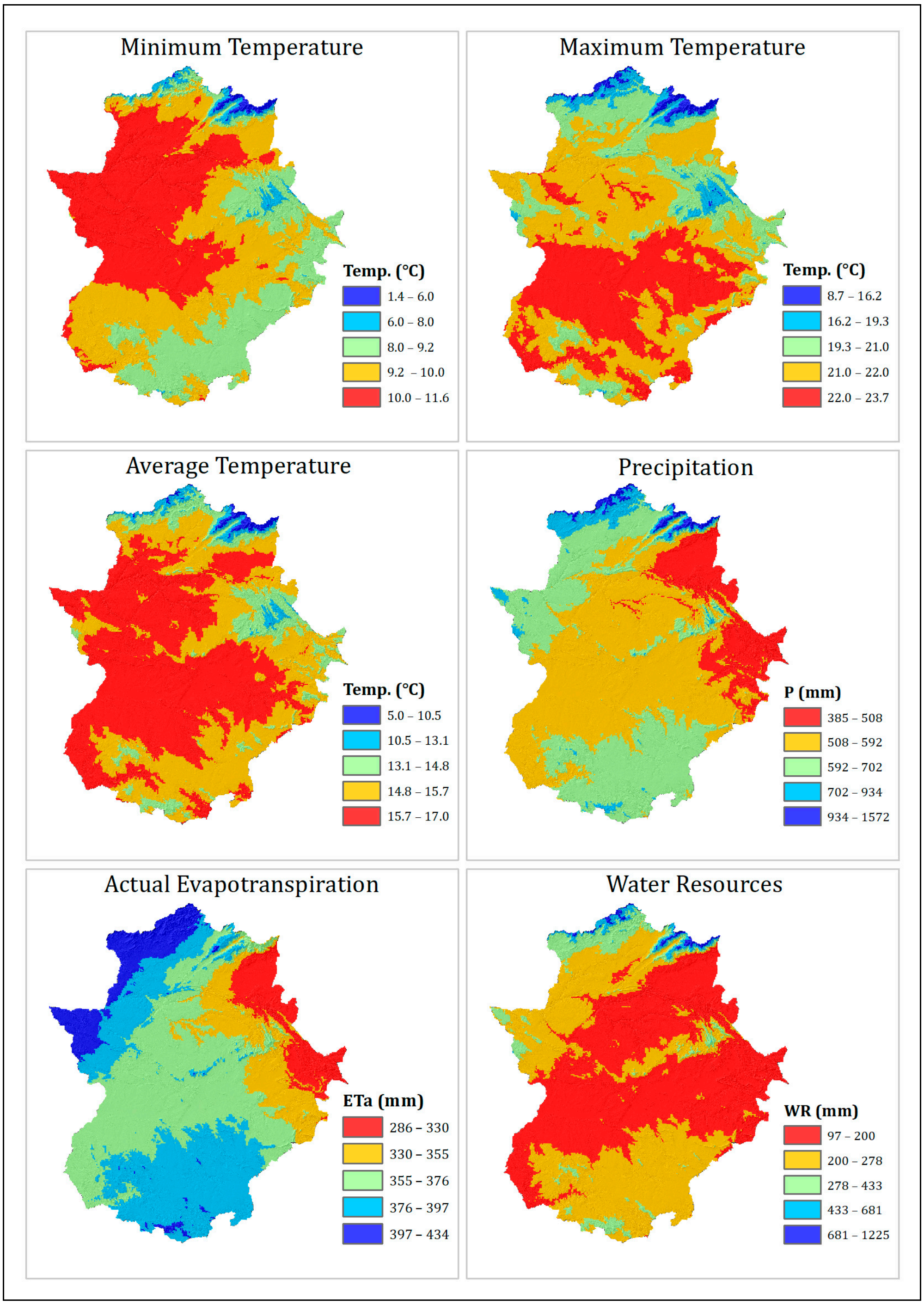

Figure 3. Climate and hydrological variables of the historical baseline period (1970–2000) in the Spanish region of Extremadura.

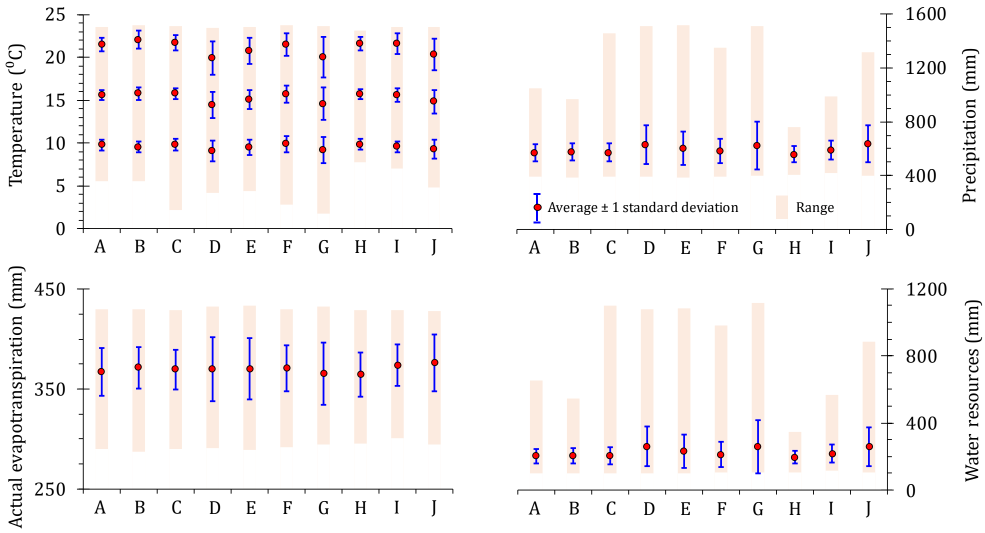

Figure 4. Climate and hydrological variables of the historical baseline period (1970–2000) according to vegetation covers. The temperature graph depicts max, mean, and min temperatures. A = Agrosilvopastoral systems (dehesas); B = Crops; C = Grasslands; D = Forests; E = Plantation Forests; F = Grasslands–Shrublands; G = Scrublands; H = Grassland with scattered trees; I = Crops with scattered trees; J = Shrublands with scattered trees.

Precipitation showed values of 584.4 ± 96.2 mm and a relatively heterogeneous spatial distribution (Figure 3). Rainfalls lower than 600 mm were observed in 64.8% of the region, while those greater than 700 mm were only observed in 6.3% of the territory (areas with altitudes higher than 690 m). The vegetation covers of forests and dehesas showed average precipitations of 630.8 and 569.9 mm, respectively (Figure 4).

The mean temperatures were 15.5 ± 1.1 °C in the region (Figure 3). Their spatial distribution exhibited relative homogeneity and a strong dependence on the orography (a correlation analysis showed the close negative relationship between the mean temperature and elevation, where 86.4% of the variance observed in the mean temperature was explained by the orography). Nearly half of the region (47.7%) ranged between 15.0 and 16.0 °C. Only ≈1% of the region (areas with altitudes higher than 1000 m) were lower than 10.5 °C, while 35% were greater than 16.0 °C. According to Figure 4, vegetation covers with the lowest average temperatures were forests (14.5 °C), while the highest ones were croplands (15.8 °C).

4.2. Future Water Resources and Hidroclimate Variations

The water resources showed decreases for all the scenarios and periods analyzed regarding those observed in the historical baseline period (Figure 5). The smallest decreases were noted during the period 2041–2060 for SSP2-4.5, where almost 74% of the region decreased between 15 and 18% (with an average decline of 16.4%). Additionally, in early periods (2021–2040) for SSP2-4.5 and SSP5-8.5, declines averaging 17.7% and 17.0% were observed, respectively.

In the late twenty-first century (2081–2100) of SSP2-4.5, a high percentage of the territory (76%) showed decreases between 27 and 33% (with an average decline of 30.7%) compared to the historical baseline period (Figure 5). However, the strongest decreases were observed during the periods 2061–2080 and 2081–2100 for SSP5-8.5, with average declines of 41.8% and 54.3%, respectively. In the first one, decreases greater than 40% of water resources were observed in 81.9% of the region, while in the second one, reductions greater than 50% were observed in 89.7% of the region. When changes in water resources were analyzed by vegetation cover under this last situation, dehesas, crops, and grasslands showed similar decreases by around 54.5% (i.e., declined from ≈203 to ≈93 mm), while in forests, the decrease was 49.1% (from 260.9 to 132.8 mm) (Figure 6).

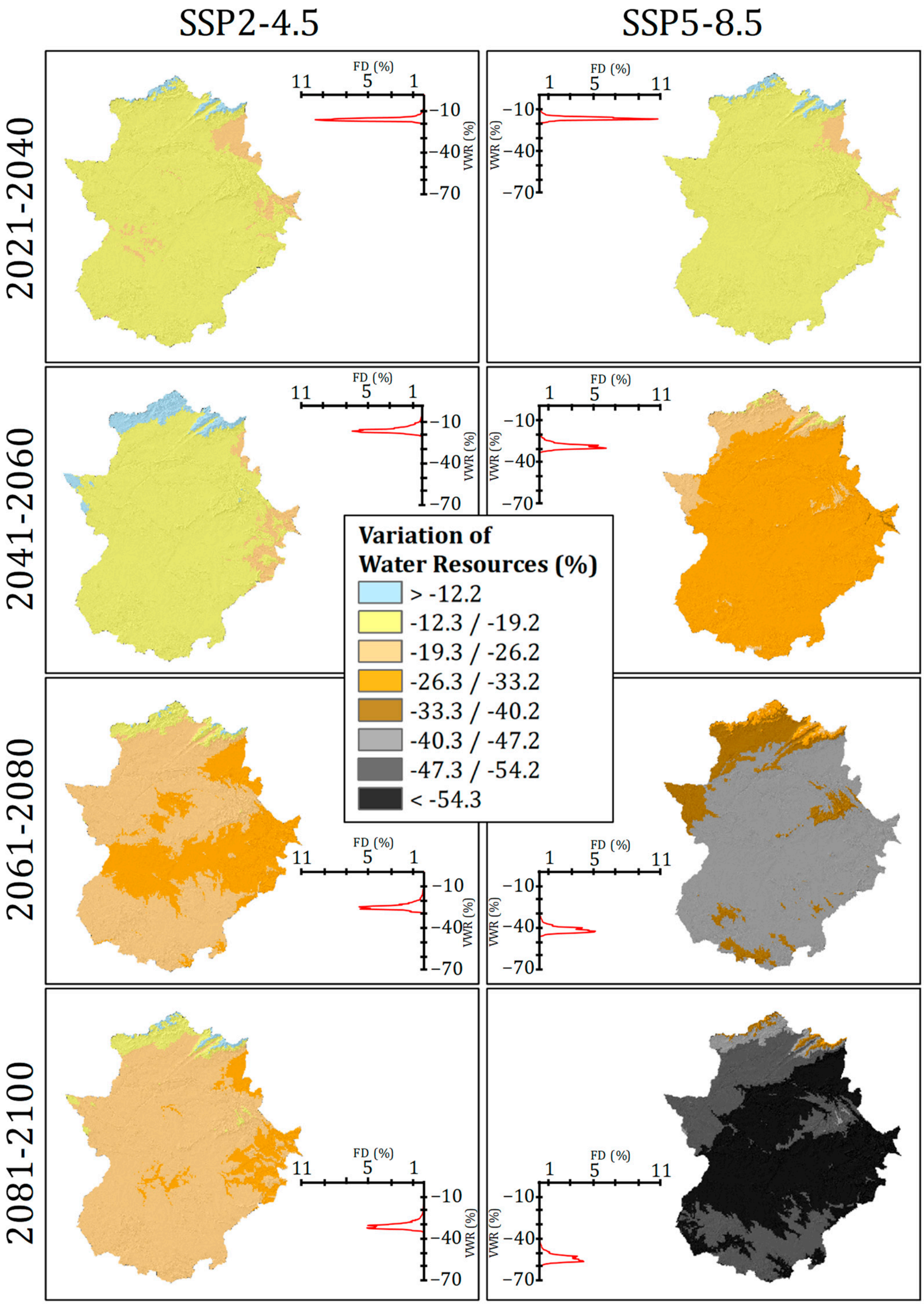

Figure 5. Changes (%) in water resources of Extremadura in different scenarios and periods. Maps were obtained by calculating differences between multi-model mean and the historical baseline period (1970–2000). Histograms were obtained from values of pixels of these maps. FD = Frequency distribution (%); VWR = Variation of water resources (%).

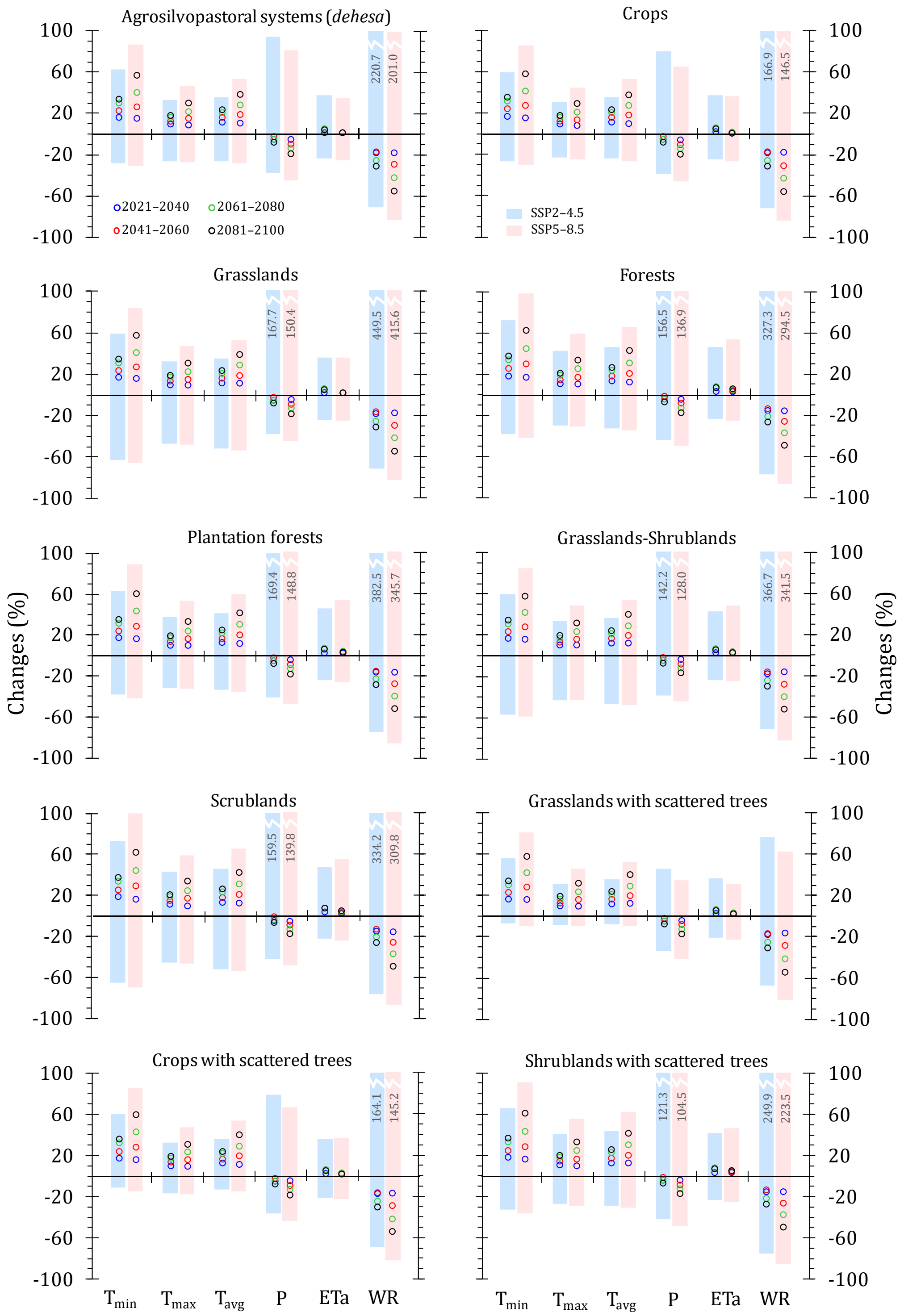

Figure 6. Changes (%) between the historical baseline period (1970–2000) and future projections (represented by colored dots) considering two scenarios, SSP2-4.5 and SSP5-8.5 (showed by colored bars, which also depict the minimum and maximum range of each variable). T_{min}, T_{max}, and T_{avg} = minimum, maximum, and average temperatures, respectively; P = Precipitation; ETa = actual evapotranspiration; WR = water resources.

The decline in water resources was related to the variations in hydroclimatic variables. Precipitation always showed decreases regarding those observed in the historical baseline period (Figure 6). The greatest precipitation decreases were observed during 2081–2100 for SSP5-8.5, with a reduction averaging 18.4% in the region. If analyzed by vegetation cover, rainfall decreased by 18% in dehesas (from 569.9 to 467.1 mm); 18.4% in crops (from 576.3 to 470.3 mm); 18% in grasslands (from 571.9 to 468.7 mm); and 17.1% in forests (from 630.8 to 522.9 mm).

Conversely, temperatures (means, maximums, and minimums) always increased for future projections compared to those observed in the historical baseline period (Figure 6). The slighter increases in mean temperatures were observed during 2021–2040 for SSP5-8.5, averaging a rise of 11.7% for all the region. Under this same situation and by vegetation covers, mean temperatures increased by 11.4% in crops (from 15.8 to 17.6 °C); 11.5% in dehesas (from 15.6 to 17.4 °C); and 12.5% in forests (from 14.5 to 16.3 °C). The greatest increases in mean temperatures were observed during 2081–2100 for SSP5-8.5, averaging a rise of 40.3% in the region compared to the baseline period. In this scenario and by vegetation covers, the increases averaged 43.0% in forests (from 14.5 to 20.7 °C); 39.4% in dehesas (from 15.6 to 21.8 °C); and 39.3% in crops and grasslands (from 15.8 to 22.0 °C). Likewise, there was a great increase in minimum temperatures (Figure 6). As an example, the smallest rises were observed during 2021–2040 for SSP5-8.5, with an average of 16.4% in the region. However, the greatest increases were observed during 2081–2100 for SSP5-8.5, with 59.7% in the region. This means that minimum temperatures in dehesas increased by 57.6% (from 9.8 to 15.4 °C), while in forests the increase was 62.5% (from 9.1 to 14.8 °C).

5. Discussion

The water resources of Extremadura showed decreases in all the scenarios and periods analyzed compared to those observed in the historical baseline period (Figure 5). This result agrees with future climate projections for the Iberian Peninsula, which show a conversion towards drier conditions, characterized by reduced precipitation, higher temperatures, and longer dry seasons [8,41]. However, the observed decrease in water resources varied according to the different scenarios and periods analyzed (Figure 5). The SSP2-4.5 scenario exhibited smaller decreases compared to SSP5-8.5, illustrating the effect of the greenhouse gas (GHG) emissions policies of SSP2-4.5, which aim to maintain the current emission levels until 2050 before declining towards net zero by 2100 [30,31]. This effect has also been observed in different studies such as those carried out by Trancoso et al. [42], Haddeland et al. [43], Konapala et al. [44], and Pokhrel et al. [3], who found that, in the Mediterranean area, declines in terrestrial water resources were greater in pessimistic scenarios than in the opposite ones. In addition, they found that decreases in water resources were lower in the early period of different scenarios than for those in the late twenty-first century, which is likely to be due to its temporal proximity.

Spatial variations of water resources were also observed in all future scenarios and periods analyzed (Figure 5). The greatest changes were observed in the SSP5-8.5 scenario over 2081–2100, in which 90% of the regional surface area showed a decrease in water resources of greater than 50%. This long-term hydrological change was mainly triggered by the strong decline in annual precipitation and the slight increase in actual evapotranspiration (Figure 6). A similar finding was reported by Greve et al. [45] for southwest Spain, where climate patterns will tend to be drier due to the changes in precipitation and evapotranspiration rates. This will lead to an increase in dryland areas, such as has also been observed by Huang et al. [46], who found that the projections under representative concentration pathways (RCPs) RCP8.5 and RCP4.5, will increase the global drylands by 23% and 11%, respectively. Similar results to those presented here were found by Moral et al. [47] in Extremadura, where they observed a progressive increase in aridity conditions in the latter part of the century, mainly under the most pessimistic scenarios.

The climate variations observed in this study could induce significant changes in the composition and spatial distribution of vegetation covers. Although Mediterranean ecosystems have developed mechanisms to cope with water scarcity and high temperatures, some species could have difficulty surviving under the shifting climatic conditions. For example, in the grasslands or dehesas, water constitutes a critical limiting factor because its availability directly determines the growth of above and belowground biomass. Thus, some studies, such as the one carried out by Lozano-Parra et al. [15], found that when environmental conditions become drier than normal, the productivity of herbaceous biomass can decrease by up to 50% because of the decline in soil moisture. Likewise, the main tree species of these ecosystems, *Quercus ilex* and *Quercus suber*, have strategies based mainly on the access to water stored in the deep layers of the soil [48–50]. Similarly, species like *Quercus pirenaica* predominate forest areas, and they depend on a water reserve that increases and is recharged mainly in winter [51,52]. Both a decrease in precipitation or an increase in severe weather events (in frequency, intensity, and duration), such as heat waves or droughts, could compromise the growth and maintenance of vegetation due to increases in water scarcity, alterations in the germination of seeds and early survival, shifts in phenology. and changes in soil fertility [53]. This could trigger shifts in the composition and distribution of vegetation covers, reduced ecosystem resilience, vulnerability to wildfires, and changes in the function of ecosystems as carbon sinks [4,8], compromising, therefore, their environmental and economic functions.

Water resources have also displayed changes in croplands and agricultural areas (Figures 5 and 6), which strongly depend on the water availability for their maintenance. Traditionally, they have been able to adapt to the changing contexts by using tools like technology and optimization resources [54]. In addition, the water resources of Extremadura, such as river flows, are regulated heavily by dams [13]. However, the degree of the changes could overcome the adaptive capacity of the agricultural sector. If both precipitation and water resources tend to decline, such as has been predicted by all the scenarios (Figure 6), irrigation campaigns could be compromised and trigger adverse situations for both maintenance and the economies associated with the use of these spaces.

The mechanisms, feedback loops, and interconnections that control the Earth's climate system are still not fully understood, so models can still be more accurate [30,31]. This can confer a certain degree of unpredictability and uncertainty on the results here presented. Because model-based projections to assess future water resources can largely differ, most studies conclude that using different scenarios and different hydroclimate models, especially on local and regional scales, is needed [55]. These results suggest that more research should be carried out to quantify the impact of climate change on the water resources at regional scales, focusing also on changes at seasonal timescales.

6. Conclusions

The water resources for vegetation structures are expected to be modified in southwestern Spain via climate change. This study explored these variations in the Spanish region of Extremadura by determining the changes in the quantity and spatial distribution of water resources for vegetation covers according to different periods and scenarios of climate change. For this, five downscaled global climate models from CMIP6 were used in four future periods (from 2021 to 2100) following two different scenarios, the SSP-2.45 and SSP-5.85. The projections were compared to a historical baseline period (1970–2000) to determine the differences in water resources.

The results show that the water resources in the historical baseline period (1970–2000) were on average 213 mm, with the geographical distribution showing relative homogeneity (94% of the territory presented water resources lower than 300 mm) and spatial variations partially related to the local orography. The vegetation covers with the greatest water resources were forests (261 mm), while the most widely spread vegetation covers, the dehesas, recorded slightly lower resources than the mean for the region (203 mm).

The climate change projections exhibited decreases in the water resources for all the scenarios and periods analyzed compared to those observed in the historical baseline period. The declines were lower in the early period of both scenarios than in the late twenty-first century. The most modest declines were during 2041–2060 for SSP2-4.5, with decreases of between 15 and 18% in around 74% of the region. The greatest decreases were during 2081–2100 for SSP5-8.5, where 90% of the regional surface area displayed declines of water resources of greater than 50%. In this last situation, the most widespread vegetation covers (dehesas, grasslands, and crops) underwent similar declines of around 55% of their water resources (from ≈203 to ≈93 mm). In the fourth widespread ecosystem, forests, the water resources declined by 49.1% (from ≈261 to ≈133 mm).

If these future projections occur, the composition and distribution of these ecosystems could be compromised. To adapt ecosystem management to the temporal variability of water resources, it will be necessary to continue monitoring climate trends and land cover.

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