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Review

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Future Agricultural Water Availability in Mediterranean Countries under Climate Change: A Systematic Review

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Abstract: Warming and drying trends in the Mediterranean Basin exacerbate regional water scarcity and threaten agricultural production, putting global food security at risk. This study aimed to review the most significant research on future water availability for the Mediterranean agricultural sector under climate change (CC) scenarios published during 2009–2024. Two searches were performed in the Scopus and Web of Science databases, to which previously identified significant studies from different periods were also added. By applying a methodology duly protocoled in the PRISMA2020-based guideline, a final number of 44 particularly relevant studies was selected for review. A bibliometric analysis has shown that most of the published research was focused on Southwestern European countries (i.e., Spain, Italy, Portugal) and grapevine and olive tree crops. Overall, the reviewed studies state that future Mediterranean water reserves may not meet agricultural water demands, due to reduced reservoir inflows and higher irrigation demands under future CC and socioeconomic scenarios. Regarding adaptation measures to improve water-use management in agriculture, the majority of the reviewed studies indicate that the use of integrated modelling platforms and decision–support systems can significantly contribute to the development and implementation of improved water/land-management practices.

Keywords: adaptation measures; agricultural water; climate change; decision–support systems; grapevine; integrated modelling; Mediterranean; olive; socioeconomic development; wheat

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1. Introduction

Agriculture is one of the most vital activities in the world. Through livestock breeding and crop cultivation, it warrants the world population's food needs and gives society food security, essential for the development of all other socioeconomic sectors [1,2]. To ensure the production of enough food to feed the global population, agricultural systems require the use of vast water resources, specifically, 69% of the total renewable freshwater yearly withdrawals, corresponding to 43,000 km^3 of water volume, or 39% of the total annual precipitation falling on land [3]. Water has several distinct applications in agriculture but is mainly used for crop irrigation and livestock breeding. A 2012 report from FAO [4] estimated that 5.1% of the total renewable water resources worldwide were used as irrigation water, although this value is thought to be vastly underestimated [5]. Deutsch et al. [6] stated that livestock uses approximately 10% of the annual global water flows. There is also a large, indirect use of water through energy consumption, given that the agri-food sector is responsible for 30% of the global total energy consumption [7], and approximately 90% of global energy generation is water-intensive, with power plants' cooling alone being accountable for 43% of the total freshwater withdrawals in Europe [8].

1.1. Climate Change Impacts on Mediterranean Water Resources

In recent years, the agricultural sector has faced unprecedented challenges driven by climate change [9]. Extreme climate and weather events, such as droughts, heavy precipitation and heat waves, are becoming more frequent and intense, leading to more crops being destroyed or lacking fresh water for longer periods [10]. Hence, besides the food supply to the world population being compromised by the loss of crop yields and impacts on the crops' phenological development, water consumption can also increase, while global water resources are becoming scarcer [11,12].

The Mediterranean Basin is one of the most affected regions worldwide by ongoing climate change and extreme atmospheric events. This region, located approximately between 30° N and 45° N of latitude and 6° W and 35° E of longitude, is mainly characterized by warm/hot dry summers and mild winters (climates known as *Csa* or *Csb* in the Köppen–Geiger climate classification system) over the Southern European coastal regions, some strips along the North African coast and part of the Middle East, or by arid climates, with hot and dry conditions all year round (known as *BWh* in the Köppen –Geiger climate classification system), over the North African regions [13,14]. Two of the main crops cultivated in the Mediterranean region are olive trees and grapevines. Between 2019 and 2021, the Mediterranean European countries produced, on average, 2 million tonnes of olive oil and approximately 137 million hectolitres of wine per year [15,16].

The occurrence of extreme precipitation in the Mediterranean region is mainly due to cut-off lows [17] and warm-core mesoscale cyclones that are occasionally generated over the Mediterranean Sea, known as "medicanes" [18,19]. Research by Ferreira et al. [20] has shown that cut-off lows are the main driver of extreme precipitation events in the southeast Spanish region of Valencia, leading to at least two consecutive days of precipitation, and occurring mainly from September to November. Moreover, this research states that cut-off low precipitation may increase by up to 88% in Northeastern Spain and 61% in the surrounding Mediterranean Sea. Claro et al. [21] also detected an increase in the extreme precipitation contribution to the total annual precipitation over South-eastern Spain, as well as in the total annual precipitation itself, which can be related to either cut-off lows or "medicane" occurrences. Manning et al. [22] analysed the co-occurrence of long-duration meteorological droughts with extremely high summertime temperatures in Europe during 1950–2013. They found these compound events are becoming hotter, more likely and longer in Southeastern Europe. Similarly, Vicente-Serrano et al. [23] have concluded that between 1961 and 2011, the frequency and severity of hydrological drought events in the Iberian Peninsula increased, due to temperature rise and consequent positive trends in atmospheric evaporative demand. Following this increased drought severity, forest and vegetation systems, which depend heavily on soil water, have presented a decrease in growth [24,25]. Moreover, future climate scenarios hint at more severe, recurrent and longer drought events, particularly in a +3 °C warming scenario, which could put this region of Southern Europe under an almost permanent state of drought [26]. If the projected scenarios of temperature increase and precipitation decrease for the Mediterranean region do occur, a decline in streamflow and soil water content will most likely occur, including significant changes in the intra-annual river regime and reservoir inputs [27].

1.2. Motivation

With the rapid increase of the global population, and its transition from a starch-based diet to a water-demanding meat and dairy diet, resulting from increases in the population's purchasing power, it becomes clear that the agricultural sector needs to urgently adapt [28]. Governments and agricultural stakeholders must integrate agri-food production within the ecosystems in a way that not only ensures their protection but also uses their potential to improve the production of the sector, instead of destroying them in a quest for more food. An example of this would be the use of river basins as cross-sectoral resource management units, where water consumption by the different professional and socioeconomic sectors is managed in a combined way [29]. Moreover, according to a literature review performed

by Velasco-Muñoz et al. [30], several authors defend the need to use multidisciplinary approaches to achieve sustainability in water management. Green infrastructure and efficiency measures can be applied to the agri-food production chain, such as the use of smart irrigation systems, preservation of coastal wetlands to act as natural barriers to flooding and erosion and regulate water flow, construction of land dams for capturing water runoff in arable fields, plantation of forests to protect the soil and improve groundwater recharge, and rainwater harvesting [31]. Within the crops themselves, farmers can also change the crop species, sowing date, cultivar and fertilisation, as well as improve disease control [32]. Further, a comprehensive adaptation to the amount of agricultural water available in the future also requires anticipating and considering the potential future climate and weather conditions. This is essential not only to project the damages that extreme atmospheric events can cause to crops, but also to forecast the amount of water that will reach the soil, through precipitation, and then be absorbed by it and by the crops (soil–water balance). Hence, atmospheric and hydrological models are critical tools in the transition to a more climate-smart agri-food sector.

Considering the importance of water to the agricultural sector and the high susceptibility of the Mediterranean region to extreme atmospheric events, the Mediterranean countries are among those where future water-use adaptation measures are most needed. Hence, this study aimed to review the most significant research of the last decades regarding water availability in the Mediterranean region. By reviewing the published research, a general view of the Mediterranean Basin water availability under future climate scenarios can be established, which includes adaptation measures proposed by the scientific community. Although reviews on this topic have already been published, a wide range of new findings and evidence arising from the rapid development of this topic are worth systematising. Furthermore, the present review will give particular attention to research that includes hydrological and/or atmospheric modelling.

2. Methodology and Gathered Data

The methodology applied in this research comprised searching and gathering published studies related to water availability in the Southern Europe/Mediterranean agricultural sector within two widely used databases in this field, namely the Scopus and Web of Science (WoS) web platforms. We used both the Scopus and Web of Science databases to cover a wider scope of journal publications, since some publications could not be included in Scopus, but could be included in Web of Science, and vice-versa. Each step of the methodology was described through a guideline established in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses version 2020 (PRISMA 2020) statement [33], a widely used guideline for systematic reviews. By describing the methodology procedures, it can be assured that the workflow and the research results can be equally achieved in future reviews, or by third parties.

The first step of our methodology comprised establishing a search equation that included crucial keywords related to our research topic. They needed to reflect: (1) the review's target area, i.e., the Mediterranean (and especially Southern Europe) and (2) the subject, i.e., water availability in the agricultural sector under a climate change future. The search equation presented in the upper row of Table 1 was established. In this equation, words succeeded by an asterisk were used to cover all its possible variations. The term ""south* europe" OR "Mediterranean"" ensures the identification of studies with the Mediterranean or southern European countries as study areas. Then, the terms "agriculture OR crop* OR viticulture OR olive OR maize OR wheat OR almond OR corn" were chosen to gear the database search engines towards studies on the predominant crop types in the Mediterranean Basin countries. Additionally, within the results obtained with those two terms, the terms "water OR irrigation" and "clima* change" facilitate the identification of studies assessing agricultural water availability and crop water consumption under climate change scenarios. With this equation defined, simultaneous searches were performed on both Scopus and WoS platforms on two different dates. The first search was conducted on

10 January 2024 and resulted in 1127 and 1116 records obtained from the Scopus and WoS websites, respectively.

Table 1. Web databases and the two search equations used.

Databases	Websites	Access Date	Search Equation
Scopus and Web of Science	https://www.scopus.com / https://webofscience.com	10 January 2024	("south* europe" OR mediterranean) AND (water OR irrigation) AND (agriculture OR crop* OR viticulture OR olive OR maize OR wheat OR almond OR corn) AND ("clima* change")
		30 January 2024	("south* europe" OR mediterranean) AND (water OR irrigation) AND (agriculture OR crop* OR viticulture OR olive OR maize OR wheat OR almond OR corn) AND ("clima* change") AND ("crop* model*" OR "hydro* model*")

Due to the large number of records obtained, it was decided later to add the term "crop* model*" OR "hydro* model*" to the equation, to focus the search on studies that used numerical modelling to assess either future crop water consumption (crop modeling) or agricultural water availability (hydrological modeling). Climate modeling is indirectly included in the search equation by the term "clima* change". As such, on 30 January 2024, a second search was made with the updated search equation presented in the lower row of Table 1. In this latter case, only 93 and 101 records were obtained from Scopus and WoS, respectively. Given that this is a relatively small number of articles for a review, we opted to use the results of both searches in the subsequent stages of our analysis.

Afterwards, the guideline presented in the PRISMA 2020 flow diagram of Figure 1 was applied to the initial records found in the two searches, to find the most relevant publications on the research subject in question. The process described in Figure 1 was composed of three main stages: "Identification," "Screening" and "Included". In the "Identification" stage, the records were downloaded in CSV format for bibliometric analysis and the construction of infographics. Some of these records were previously identified through other databases (e.g., Google Scholar), and are accounted for in the "Identification through other methods" section of the diagram. Afterwards, records were excluded through the Scopus and WoS websites' search criteria, such as subject areas/categories, keywords, citation topics, document language, type of publication, year of publication and publication stage. Only journal article publications written in English and published in the previous 15 years (i.e., between 2009 and 30 January 2024) were considered. The subject areas/categories, keywords and citation topics selected in the Scopus and WoS databases are shown in Tables 2 and 3, respectively. Duplicate records were also removed during this stage.

Table 2. Subject areas and keywords selected on the Scopus website.

Subject Areas	Keywords
"Environmental Science" "Agricultural and Biological Sciences" "Earth and Planetary Sciences" "Multi-disciplinary"	"Adaptation", "Adaptive Management", "Agriculture", "Agricultural Irrigation/Modeling/Production", "Agronomy", "AquaCrop", "Climate", "Climate Change", "Climate Change Projections/Scenarios/Impact", "Climate Conditions/Effect/Variation", "Climate Models/Modeling/Modelling", "Crop(s)", "Crop Model/Modeling/Modelling", "Crop Plant/Production/Yield", "Cultivation", "Drought(s)", "Drought Stress", "Evapotranspiration", "Flowering", "Future Climate", "General Circulation Model", "Global Change/Warming", "Growth", "Growing Season", "Hydrological Model/Modeling/Modelling", "Hydrology", "Irrigated Agriculture", "Irrigation", "Irrigation Requirements/System", "Numerical Model", "Precipitation", "Productivity", "Rain", "Rainfall", "Rainfed Agriculture", "Reservoirs (water)", "Reservoir Management", "Runoff", "Seasonal Variation", "Soil Water", "Soil and Water Assessment Tool", "STICS", "SWAT", "SWAT Model", "Vitis", "Water", "Water Availability/Conservation/Demand/Resource(s)/Scarcity", "Watershed(s)", "Water Stress/Supply/Use", "Water Use Efficiency", "Wheat", "Yield", "Yield Response"

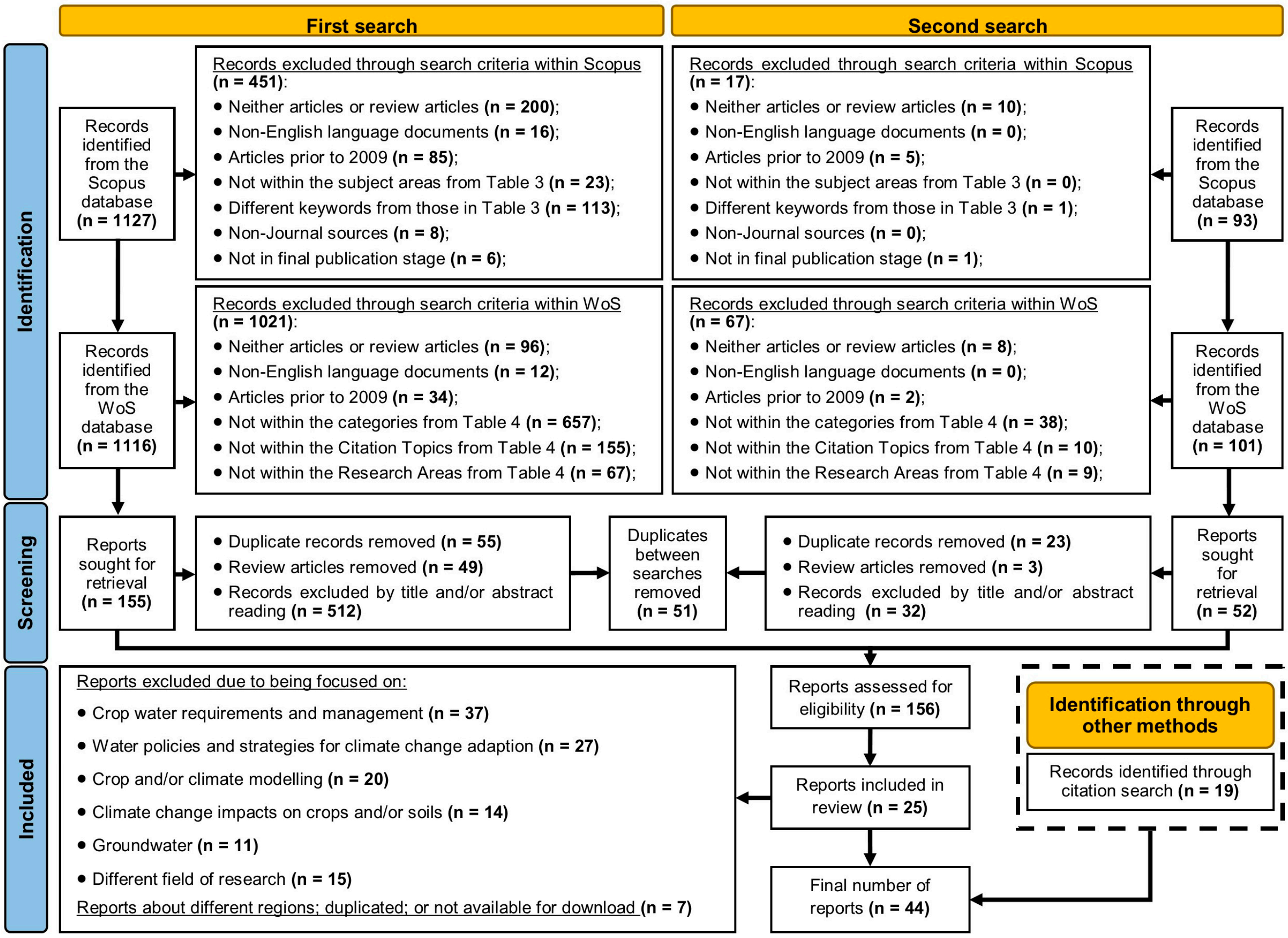

Figure 1. PRISMA 2020 flow diagram of the methodology used to select the most adequate reports for review, retrieved from the Scopus and Web of Science (WoS) web databases.

Table 3. Categories, citation topics, and research areas selected on the Web of Science website.

Categories	Citation Topics Meso	Citation Topics Micro	Research Areas
"Environmental Sciences" "Agronomy" "Water Resources" "Agriculture Multidisciplinary" "Computer Science Interdisciplinary Applications" "Meteorology Atmospheric Sciences"	"Oceanography, Meteorology & Atmospheric Sciences" "Crop Science" "Soil Science" "Climate Change" "Water Resources" "Crop Protection" "Environmental Sciences"	"Evapotranspiration" "Grain Yield" "Water Governance" "Groundwater" "Climate Change Adaptation" "Growth Regulation" "Stormwater" "Climate Security" "Reservoir Operation" "Science Communication" "Heat Waves"	"Agriculture" "Water Resources" "Meteorology Atmospheric Sciences"

The "Screening" stage of the guideline comprised an initial screening of the resulting records by reading their title and abstracts. This led to the exclusion of any articles that met the criteria previously mentioned but were not relevant to the topic of this research. Review articles were also excluded, and the remaining records of both searches were merged, with duplicates removed. This led to 156 records being eligible for the "Included" stage. This last stage comprised a more detailed reading of the remaining records to decide which were the most relevant to include in our general assessment of future water

availability and crop water needs in the Mediterranean Basin countries. It was decided that the most important records for the review should concurrently cover water availability assessments, agricultural water consumption, hydrological simulations and future climate projections. The records that focused mainly, or solely, on the following topics were thus excluded: crop water requirements and management; water policies and strategies for climate change adaption; crop and/or climate modelling; climate change impacts on crops and/or soils; groundwater; not within the region of interest (i.e., Mediterranean Basin countries); duplicated; or not available for download.

By applying these exclusion criteria, a final number of 44 reports was achieved. These reports, and their respective years of publication, studied areas and main research topics, are listed in Table 4. The research topics were divided into 7 categories: (1) Reference studies; (2) Climate, socioeconomic development and land-use management impacts on water availability; (3) Historical and/or future water availability assessments; (4) Climate impacts on irrigation demands and management; (5) Climate change adaptation practices; (6) Integrated modelling frameworks; and (7) Decision-support systems.

Table 4. Final list of reports reviewed after the application of the PRISMA2020 methodology guideline. The reports' reference number is presented in the first column, followed by the year of publication, studied areas and the main research topic. Research topics were divided into 7 categories: (1) Reference studies; (2) Climate, socioeconomic development and land-use management impacts on water availability; (3) Historical and/or future water availability assessments; (4) Climate impacts on irrigation demands and management; (5) Climate change adaptation practices; (6) Integrated modelling frameworks; (7) Decision-support systems.

Refs.	Year	Studied Areas	Topic	Refs.	Year	Studied Areas	Topic
[34]	1989	Africa	(1)	[60]	2019	Tâmega Basin (Portugal)	(2); (3)
[35]	1999	Worldwide	(1)	[61]	2023	Côa Basin (Portugal)	(4)
[36]	2000	Worldwide	(1)	[62]	2017	Vale do Gaio reservoir (Portugal)	(4)
[37]	2003	Worldwide	(1)	[63]	2020	Alentejo (Portugal)	(2); (5)
[38]	2003	Worldwide	(1)	[65]	2010	Southern Italy	(2)
[39]	1999	Europe	(1)	[67]	2012	Northern Italy	(2)
[40]	1985	None	(1)	[68]	2018	Gediz Basin (Turkey)	(2)
[41]	2002	Worldwide	(1)	[69]	2019	Gediz Basin (Turkey)	(2)
[42]	2002	Worldwide	(1)	[71]	2020	Nebhana dam (Tunisia)	(4)
[43]	2004	Worldwide	(1)	[72]	2022	Haouz Plain (Morocco)	(4)
[44]	2007	Worldwide	(1)	[73]	2017	Algarve (Portugal)	(2)
[45]	1999	Mediterranean countries	(1)	[74]	2023	Sorraia Basin (Portugal)	(5)
[46]	2002	Mediterranean countries	(1)	[75]	2019	Southern Europe	(5)
[47]	2007	Mediterranean countries	(1)	[76]	2021	Europe	(6)
[48]	2013	Mediterranean countries	(5); (3)	[77]	2024	Akmese dam (Turkey)	(6)
[49]	2011	Catalonia (Spain)	(3)	[78]	2017	Lake Beyşehir (Turkey)	(6)
[51]	2013	Ebro Basin (Spain)	(3); (6)	[79]	2021	Sardinia (Italy)	(2)
[53]	2010	Northeast Spain	(2); (3)	[80]	2019	Central Spain	(2)
[54]	2015	Ebro Basin (Spain)	(4)	[81]	2013	Hérault Basin (France)	(6)
[56]	2012	Júcar Basin (Spain)	(3)	[82]	2017	Southern Italy	(7)
[57]	2018	Tagus Basin (Spain)	(2); (3)	[83]	2019	Crete (Greece)	(7)
[59]	2022	Almeria (Spain)	(2); (3)	[84]	2023	Spain, Tunisia, Lebanon	(7)

Bibliometric Analysis

During the application of the methodology to the records identified in the first search, a bibliometric analysis of the title words and keywords of each record was also made. The goal of this analysis was not only to identify the most studied countries, regions and crops concerning our research topic but also to identify the main research topics and guidelines. Therefore, this bibliometric analysis comprised a word count of the most used terms and country names in the title words and keywords (hereafter title/keywords) of the first search records. This bibliometric statistical analysis was only undertaken for the first

search records, as the large majority of the second search's records were already identified in the first search and were a much smaller number. As a result of the aforementioned bibliometric analysis, several information graphics were produced. Figure 2 presents a word count of the name of each Mediterranean country targeted in the records.

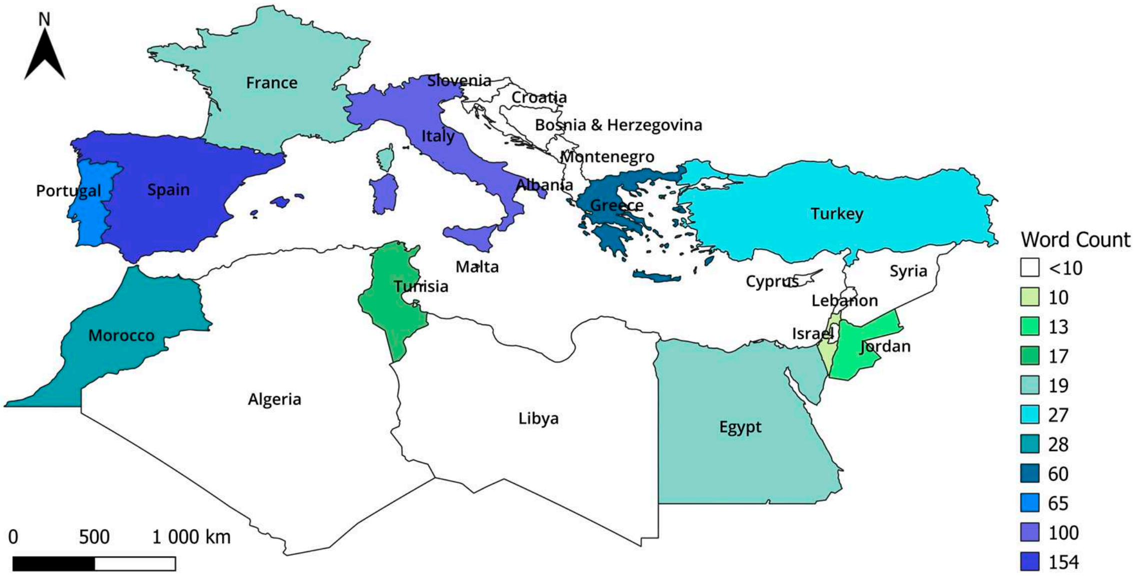

Figure 2. Word count of the name of each Mediterranean country, and all its derivatives, appearing in the title/keywords of the records identified in the first search.

The results show that the Mediterranean countries most subjected to research on agricultural water are Spain, Italy, Portugal, Greece, Morocco, Turkey, France, Egypt, Tunisia, Jordan and Israel. Spain is mentioned the most, with 154 occurrences in all the record title/keywords and variations of its name. It is followed by Italy, Portugal and Greece, whose names are referred to 100, 65 and 60 times, respectively. Morocco and Turkey are cited 28 and 27 times, respectively. France and Egypt are equally mentioned: 19 times. As for Tunisia, Jordan and Israel, they are mentioned 17, 13 and 10 times in the title/keywords, respectively. These numbers demonstrate that European Mediterranean countries are the most studied countries of the Mediterranean Basin regarding agricultural water assessments, mainly those in Western Europe, as Portugal, Spain, Italy and France are cumulatively mentioned 338 times. It is thus expected that the final number of reports being reviewed should include study areas mostly situated in these countries. Additionally, it is important to note that during the "Identification" and "Screening" stages of our methodology, some of the identified reports were related to countries with Mediterranean-type climates. However, given that the large majority of the identified reports were related to countries within the Mediterranean Sea Basin, and our research goal was to specifically assess the climate change impacts on the future water availability of Mediterranean Basin countries, we decided not to include those reports on this review.

Besides the identification of the most studied countries and regions, an identification of the main research topics was also carried out, by grouping the title/keywords into 7 different categories, namely: crop-related (C), agricultural practices-related (A), water-related (W), temperature and aridity-related (TA), meteorology and climate-related (MC), methodology and modeling-related (MM) and management-related (M) words. A word count for each category, as well as their percentage share of the total number of titles/keywords, is presented in Figure 3. A sample of the most-found title/keywords from each category is presented in Figure 4.

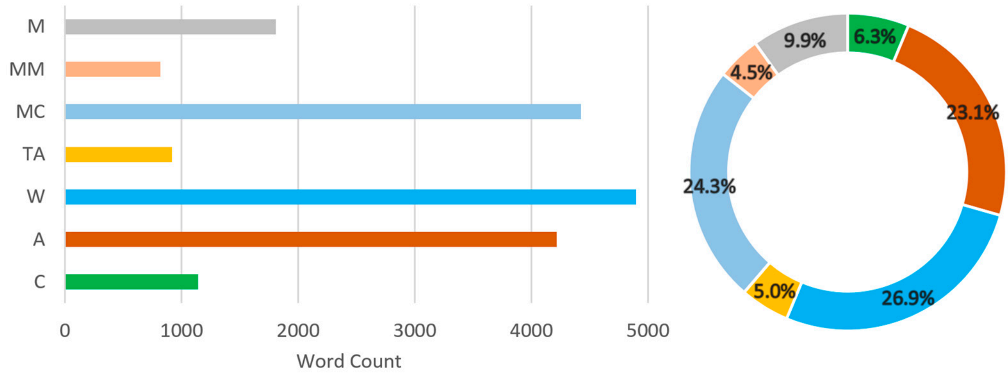

Figure 3. Word count of all the crop-related (C), agricultural practices-related (A), water-related (W), temperature and aridity-related (TA), meteorology and climate-related (MC), methodology and modeling-related (MM) and management-related (M) words appearing in the records' title/keywords, as well as the percentage share of each of those word categories.

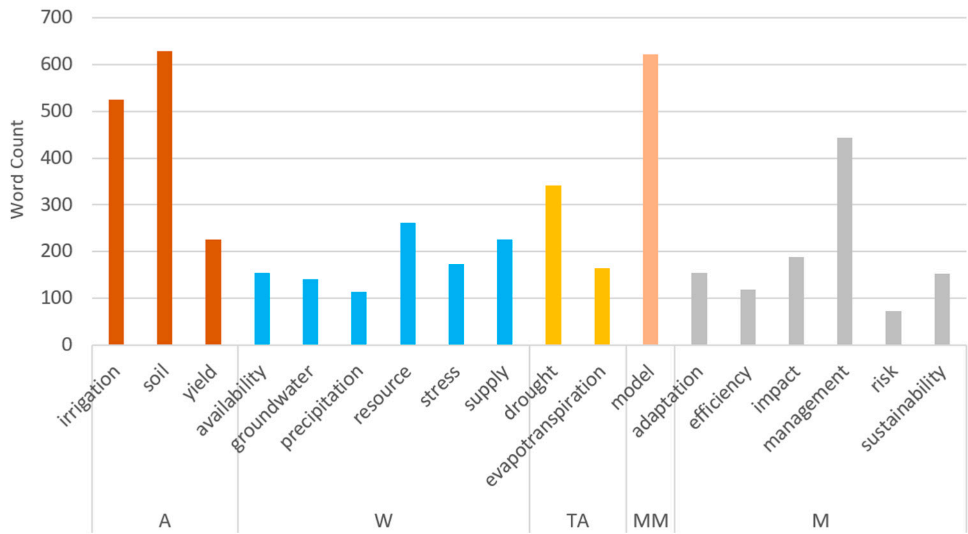

Figure 4. Main title/keywords identified in the agricultural practices-related (A), water-related (W), temperature and aridity-related (TA), methodology and modelling-related (MM) and management-related (M) words categories.

The results presented in Figure 3 show a predominance of water-related words, followed by meteorology and climate-related words, and agricultural practices-related words, each having a 26.9%, 24.3% and 23.1% share of the total number of words. Given that the present review is aimed at studies regarding agricultural water availability under future climate conditions, this was an expected outcome. Nevertheless, more interesting was the number of management-related words found, which was higher than crop-related, temperature and aridity-related and methodology and modeling-related words. This could mean that the records identified in our searches gave particular attention to management practices in the agricultural sector.

In Figure 4, some of the words were expected to appear the most, such as "soil", "availability" or "model". Others give clues on what was assessed in the identified records. For instance, through the high counting of "irrigation", "drought" and "evapotranspiration", it can be concluded that drought events, crop evapotranspiration and the need to irrigate crops were central research topics.

Similarly, due to the use of "yield" and groundwater", crop yields and the use of groundwater appear to be two other main research topics. Regarding the management-related words, "sustainability" and "risk" of crops or agricultural practices were frequently

assessed, while improving crop "efficiency" and "adaptation" were also important research subjects. As for the crop-related words, they have shown that the most referenced crops, and thus possibly the most studied crops, were vineyards, wheat, olives, maize, citrus, tomato and barley, as presented in Figure 5.

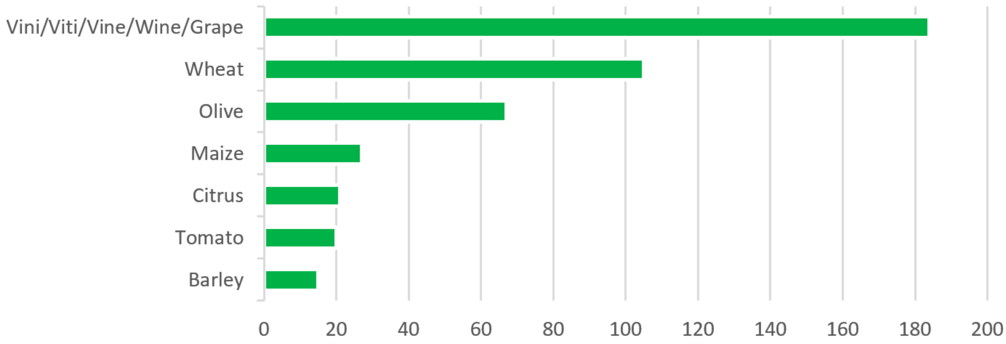

Figure 5. Main title/keywords identified in the crop-related (C) words category, and their word count.

3. Water Resources and Climate Change

The first approaches to the water reserves' vulnerability to climate change can be traced back to, at least, the latter decades of the 20th century. Early research by authors such as Falkenmark et al. [34] and Arnell [35] has opened the discussion about this topic, by assessing how climate change and population growth could impact global water resources, particularly in African and Asian countries with semi-arid climates. Specifically, Falkenmark et al. [34] concluded that in the subsequent decades, two-thirds of the African population would live in severe water stress conditions and that measures such as maximising agricultural production per water unit, using crops with lower water demand, improving water retention in the root zone or controlling population growth could be the solution to the water scarcity in this continent. Arnell [35] made a global analysis and estimated that approximately 5 billion people would live in countries with water stress by 2025 and that the average annual water surface runoff would increase in equatorial Africa and Asia, as well as in high latitudes, while in the mid-latitudes and subtropical regions it would decrease. To achieve those results, Arnell [35] used Hadley Centre climate change scenarios as input to simulations of global river flows made with a macro-scale hydrological model, hence making this research one of the first where hydrological modeling was used in combination with climate model simulations, similarly to Vörösmarty et al. [36].

The use of numerical modelling in water resources assessment would grow through the transition period from the 20th to the 21st century. In 2003, Alcamo et al. [37] developed a water use/hydrology model that considers domestic and industry water consumption, as well as the climate effects on the agricultural sector's irrigation requirements, and it can run simulations at the river basin scale for the entire globe. With this model, the same authors estimated that improvements in water-use efficiency and the saturation of water needs would lead to stabilisation, or decrease, of water withdrawals in 41% of the world's river basin areas by 2025, while socioeconomic growth would lead to increases in water withdrawal [38]. Previously, in 1999, Arnell [39] developed a macro-scale water balance model (i.e., a model that can be applied over a large geographic domain without the need to be calibrated at the catchment scale), based on a probability-distributed model developed by Moore in 1985 [40]. As the numerical models' development progressed, these were applied to more specific tasks in different sectors, such as agriculture. In 2002, Döll and Siebert [41] presented the first model able to estimate, spatially explicitly, the irrigation water requirements at a global scale, by using a global map of irrigated areas. A subsequent application of this model allowed Döll [42] to perform the first global analysis of the impact of climate change and climate variability on irrigation water requirements. They concluded that two-thirds of the world's irrigated areas existing in 1995 would experience an increase in water requirements by 3–5% or 5–8%, during the 2020s or 2070s, respectively.

At this point, the water resources projections generated by the established modeling capacity claimed adaptation strategies in the agricultural sector. Rosenzweig et al. [43] conducted one of the earliest studies about the impacts of future climate and socioeconomic changes on agricultural water resources, and possible adaptation strategies for these impacts. The authors followed an innovative approach, by combining a water supply model and the Water Evaluation And Planning (WEAP) model with three crop yield and irrigation demand models. This modeling structure was driven by a set of future scenarios, projecting changes in climate, population, agricultural production and gross domestic product (GDP) for the 2020s and 2050s time periods, and it was applied to major agrarian regions in Hungary, Romania, Brazil, Argentina, the United States and China. The results showed that, under future climate and socioeconomic scenarios, North-eastern China would be the most affected region by lack of water availability, while Brazil and the United States would maintain abundant water supplies. As for Hungary, Romania and Argentina, water stress was projected to occur only in some regions and scenarios. The adaptation tests demonstrated that only Brazil could readily accommodate an expansion of the irrigated land area, whereas Hungary, Romania, Argentina and China would see a decrease in the irrigation systems' reliability if an irrigated land expansion were to happen. Alternative cultivars were seen as a possible adaptation measure, but they could lead to an even higher water demand. Hence, the authors asserted that even in relatively water-rich areas, climate change effects on agriculture and increased urban water demand would require improvements in water management, irrigation and drainage technology. Fischer et al. [44] also assessed the effectiveness of mitigation measures to reduce socioeconomic and climate impacts on global water resources, using an agroecological model and developing a new socioeconomic scenario. Their predictions were more optimistic than those of Rosenzweig et al. [43] since it was estimated that mitigation measures could reduce by 40% the climate change impacts on agricultural water requirements when compared with unmitigated climate. It was also estimated that improved irrigation efficiency could reduce annual costs by circa USD 10 billion by 2080.

4. Future Water Availability in Mediterranean Countries

Due to its strong agricultural tradition and being one of the most affected regions by climate change, the Mediterranean region was one of the first to be subjected to future agricultural water availability research. Studies and reports such as Correia [45], Haas [46] and Iglesias et al. [47] demonstrate that during the turn of the century, water shortages driven by extreme climate and weather conditions and the improvement of water resources planning and management were already a concern for institutions and governments of the Mediterranean countries. These issues should continue to be a concern for the upcoming years, as more recent studies estimate that possible future climate scenarios could lead to increases in water stress across the entire Mediterranean Basin [48].

When looking specifically at research regarding climate and socioeconomic impacts on Mediterranean agricultural water resources, a clear increase in the amount of research on this topic can be found between the turn of the century and the 2010s and early 2020s, along with much-improved data thanks to the advancements that occurred in numerical modeling. From 2009 onwards (i.e., during the period searched by the present review), studies were published concerning agricultural water assessment over areas in almost all the Mediterranean-surrounding countries. Nevertheless, as discussed in the previous chapter, most published research focuses on Western European countries (i.e., Spain and Portugal). Furthermore, the final number of reports gathered during the methodological selection process highlights that nearly every step of the agricultural water cycle has been studied by the most recent studies, from the impacts of climate and land use changes in the headwaters of river basins to the assessment of irrigation demands and future amounts of water resources.

4.1. Spain

In the Western European Mediterranean countries, Spain has the highest number of studies regarding future water availability. In North-eastern Spain, Gallart et al. [49] conducted a temporal trend analysis of the Llobregat and Ter River headwater flows in 1940–2000, using land cover, discharge and evapotranspiration data obtained through observations and simulations with the SACRAMENTO conceptual rainfall–runoff model, as well as an evapotranspiration model developed by Zhang et al. [50]. Only the measured historical flow data presented a significant decreasing trend, which led the authors to conclude that, during the second half of the 20th century, flow decreases in those North-eastern Spanish rivers were due to an increase in forest cover around the headwaters, with no relevant changes due to climate forcing. In the Ebro Basin, the largest in North-eastern Spain, Milano et al. [51] used a modified version of the GR2M water balance model [52] and the CSIRO-Mk3.0, HadCM3, ECHAM5-MPI and CNRM-CM3 general circulation models (GCMs) to evaluate the basin's capacity to meet agricultural and domestic water demands during the 1971–1990 period, and also during the 2041–2060 period under the Intergovernmental Panel for Climate Change (IPCC) A2 scenario. They found that, although water demands in the Ebro region were satisfied during 1971–1990, water resources could decrease by 15% to 35% during spring and summer in 2041–2060. Other researchers, such as Ramos and Martínez-Casanovas [53], defend that the agricultural water supply in Northeast Spain is already under threat due to continuously increasing temperatures and very intense rainfall episodes, which according to their research appear to be correlated with major runoff losses and increases in evapotranspiration in the Pènedes winemaking region, southwest of Barcelona, consequently leading to water deficits in the grape growing period. Von Gunten et al. [54] also evaluated the climate change impacts on a sub-catchment of the Ebro Basin under different climate and irrigation scenarios, through the use of the HydroGeoSphere coupled evapotranspiration, surface water and groundwater flow model [55]. The future climate scenarios, corresponding to the 2040–2050 period, were simulated with the ETHZ, MPI, METO and UCLM Regional Climate Models (RCMs), under the IPCC A1B CO_2 emissions scenario. The 1990–2000 period was used as a reference period. Similar to the findings of Milano et al. [51], the authors concluded that by 2040–2050 water availability in the Ebro Basin will decrease relatively to 1990–2000, whereas irrigation demands will experience a 10% increase. In addition, it was observed that annual maximum peak flow could increase more in non-irrigated than in irrigated regions (thus leading to higher flood risk in non-irrigated areas), while the likely transition from rain-fed to irrigated agriculture could result in larger stream flows during dry periods.

Further south, in the Júcar Basin (eastern Spain), Ferrer et al. [56] assessed the surface water and groundwater quantities using the GeoImpress and Patrical water balance/quality models and found that water resources suffered a reduction of 18% in 1990–2010 relative to 1961–1990. Projections of future climate change impacts obtained by these authors indicated that, compared to the 1990–2000 reference period, water resources should be reduced by 19% during 2010–2040 under the IPCC A1B scenario, and by 40% to 50% during 2070–2100 under the IPCC A2 and B2 scenarios. In Central Spain, Pellicer-Martínez and Martínez-Paz [57] made hydrological model simulations of the Tagus River headwaters during a 1940–2010 reference period and a 2020–2090 future period, using the SIMGES module of the AQUATOOL decision–support system (DSS) [58] and the IPCC's Representative Concentration Pathways 4.5 (RCP4.5) and 8.5 (RCP8.5) emissions scenarios. Their results point towards significant reductions in snowfalls and aquifer recharge in the Tagus headwaters. Water resources in the Tagus Basin were forecasted to suffer a 40% decrease in the RCP4.5 scenario and a 47% decrease in the RCP8.5 scenario. Not only does this affect the Tagus Basin's natural regulation, but it also affects water resources in the neighbouring Segura Basin (Southeast Spain), due to water transfers from the Tagus to the Segura Basin. It is estimated that flows between the Tagus and the Segura could suffer a 70% to 79% reduction in both RCP scenarios when compared to a scenario without climate change, which consequently should induce economic losses of EUR 380 to 425 million per year

in the region, mainly due to decreases in agricultural production [57]. The southernmost basins of Spain should also see a strong reduction in their water reserves, such as the Almeria Basin, where Zapata-Sierra et al. [59] projected a 50% decrease in water resources during the 2020–2040 period, compared to the 2000–2020 period.

4.2. Portugal

The overall projections of increased temperatures, decreased precipitation and seasonal precipitation shifts that are observed in Spain by many researchers are also expected to occur across the border, in Portugal. Through streamflow simulations with the Hydrological Simulation Program-FORTRAN (HSPF) and future climate data from the Global Circulation Model (GCM) and Regional Climate Model (RCM) chain experiments from the EURO-CORDEX project, Fonseca and Santos [60] assessed the impacts of climate change on the flow rates of the Tâmega Basin, in Northern Portugal. The authors predicted that during the 2021–2100 period and relative to a 1950–2015 historical period, the basin-mean annual temperatures could increase by 10% and 20% under the RCP4.5 and RCP8.5 scenarios, respectively. Moreover, the 2021–2100 basin–mean annual precipitation was also estimated to decrease by 8% under RCP4.5 and 13% under RCP8.5 relative to the same historical period. Consequently, the projected changes in temperature and precipitation are expected to lead to an 18% decrease under RCP4.5, and a 28% decrease under RCP8.5, in annual flow rates in the Tâmega Basin relative to historical observations. Rodrigues et al. [61] applied a similar methodology to another Northern Portugal basin, namely the Côa Basin, intending to evaluate climate change impacts on agricultural irrigation needs. Simulations were made with the HSPF model for a 1986–2015 historical period and a 2040–2099 future period under the RCP8.5 emissions scenario, using three EURO-CORDEX GCM-RCM chain datasets. These simulations allowed the authors to detect a 30% decrease in annual flow rates by 2099 and an increase in the flow rates' interannual variability, with the winter/spring flow rates increasing and the remaining seasons' flow rates decreasing. A comparison of the future flow rates' results with projected irrigation scenarios has shown that irrigation water demands could increase by 46 to 184 $hm^3 \cdot yr^{-1}$.

In the Alentejo region of southern Portugal, Nunes et al. [62] and Rocha et al. [63] applied the Soil & Water Assessment Tool (SWAT) hydrological model to detect the impacts of future climates on water availability and the quality of several Alentejo water reservoirs. Nunes et al. [62] studied the impacts of climate and socioeconomic changes on the Vale do Gaio reservoir's water availability during 2071–2100 using future precipitation and temperature data estimated through simulations made by Serpa et al. [64] with the ECHAM5 GCM under the IPCC A1B and B1 scenarios. The A1B scenario reflects a 2.2 °C increase in daily temperature and a 9% decrease in annual rainfall, with the winter rainfall increasing by 28%. As for the B1 scenario, it reflects a 1.1 °C increase in temperature, and also a 9% decrease in annual rainfall, but with a rise in winter rainfall of around 30%. Three socioeconomic scenarios were also considered in the SWAT simulations, with each representing changes in population (4.8% decrease in population), land use (replacement of cereal and pasture crops by sunflower) and irrigation water demand (11% increase in demand). The results of the SWAT simulations have shown that climate change alone can lead to 25% and 27% decreases in reservoir inflow under the A1B and B1 scenarios, respectively, while land use changes alone can lead to inflow increases of 3% (A1B) to 7% (B1). In the combined climate and socioeconomic scenarios, inflows are expected to decrease between 19% and 23%. Irrigation water demand is also projected to increase between 3% and 21%.

More recently, Rocha et al. [63] followed a similar methodology for the Monte Novo and Vigia reservoirs, but instead used climate data generated by simulations with the EURO-CORDEX RACMO22E and RCA4 RCMs for the 1971–2000 reference period and 2010–2040, 2040–2070, and 2070–2100 future periods, under the IPCC RCP4.5 and RCP8.5 scenarios. During the 2070–2100 period, the SWAT simulations using RACMO22E data estimated that, for the RCP4.5 scenario, reservoir inflows could decrease by 8% in Monte Novo and 4% in Vigia. For the RCP8.5 scenario, reservoir inflows could decrease by 19% in

Monte Novo and 23% in Vigia. As for the simulations using RCA4 data, 49% and 42% inflow increases were projected for Monte Novo and Vigia, respectively, under the RCP4.5 scenario, while under RCP8.5 the simulations projected a 19% decrease for Monte Novo and a 7% decrease for Vigia. Regarding irrigation demand during 2070–2100, SWAT results foresee 28% and 31% increases in the RCP4.5 and RCP8.5 scenarios, respectively. Moreover, both Nunes et al. [62] and Rocha et al. [63] stated that projected land-use changes could cause an increase in phosphorous concentrations, and thus reduce the water quality. Both studies also suggested a set of adaptation and management strategies to cope with the future water availability decreases, namely the renewal of irrigation networks, satellite imagery, drones for water stress monitoring and adequate crop selection, as well as improved land-use policies.

4.3. Other European and Northern African Countries

In southern Italy, D'Agostino et al. [65] employed the DiCaSM catchment–scale hydrological model to assess climate change impacts on the hydrological cycle of the Candelaro catchment (Apulia region). The authors established 4 future climate scenarios, based on HadCM2 model simulations under the IPCC IS92a scenario made by Ragab and Prudhomme [66], and applied those climate scenarios to DiCaSM hydrology simulations. The results showed that stream flows and groundwater recharge could decrease by 16–23% and 21–31% by 2050, respectively. It was also found that future rainfall reductions and temperature increases could lead to a 2–10% reduction in durum wheat yield by 2050. In northern Italy, climate change projections with the IPCC A1B and A2 scenarios made by Mollema et al. [67] for a small agricultural watershed near the Adriatic Sea hint at an increase in water deficits during summer and an increase in water surplus during winter, owing to an increase in wintertime precipitation. Equally, during winter, researchers expect a decrease in open water evaporation under these future climate scenarios, as a result of increased winter-time relative humidity and decreased wind intensity.

In Eastern Europe, one of the most studied countries regarding future water availability for the Mediterranean agricultural sector is Turkey. Okkan et al. [68] and Gorguner et al. [69] are two examples of research on future agricultural water availability and management in this country. Both studies assessed the possible impacts of future climate change scenarios on the water inflows to the Demirkopru reservoir in the Gediz Basin (western Turkey) using the IPCC's RCP4.5 and RCP8.5 scenarios as inputs to simulations with the DYNWBM water budget model [70], in the case of Okkan et al. [68], and with the WRF-WEHY coupled hydro–climate model, in the case of Gorguner et al. [69]. The results of Okkan et al. [68] have shown a 21% reduction in reservoir inflows during 2016–2050 under the RCP8.5 scenario relative to 1996–2007, and a 16% decrease in reservoir sustainability under the same scenario. For the more moderate RCP4.5 scenario, results have shown a 15% reduction in reservoir inflows for the same period. Gorguner et al. [69] calculated the ensemble average of average annual inflow for both RCP climate projections, and contrary to Okkan et al. [68] they predicted that annual inflows should increase by approximately 22% in a near-term future period (2017–2044), 20% during a mid-term period (2045–2072) and 4% during a long-term period (2073–2100). Nevertheless, the increases become less positive with time throughout the century, and the combination of this decreasing trend with a projected temperature increase of up to 2 °C during the long-term future period could pose a threat to the irrigation water availability in the basin.

Northern African countries could also be seriously affected by future reduced water supply. In northern Tunisia, Allani et al. [71] used the WEAP model to estimate present-day and future water availability in the Nebhana dam system, with inputs from the GR2M hydrological model and future climate data from five GCMs, simulated under the RCP4.5 and RCP8.5 scenarios. The research results indicated that reservoir inflow should decrease up to 37% during 2061–2080 under both RCP scenarios, due to an 11% decrease in annual rainfall and a 6% increase in annual reference crop evapotranspiration (ET0). Moreover, the wheat growing cycle will decrease by 5%, while the citrus tree growing cycle will decrease

by 31%. Overall, Allani et al. [71] concluded that the Nebhana Dam's water reserves do not meet the system demand currently. The situation could be worsened by climate change unless better planning of the water resources is implemented. Westward, in Morocco, a very similar methodology, also including the WEAP model, was followed by Hadri et al. [72] to assess climate change impacts on water supply and demand in the Haouz plain, western Morocco. The results revealed 36% and 50% decreases in net precipitation under RCP4.5 and RCP8.5, respectively, and a 22% increase in unmet water demand in 2050, relative to a 2010–2017 baseline period and for the 'business as usual' and RCP8.5 scenarios of the WEAP and GCM model simulations, respectively. This translates into an increased water resource depletion that is projected to reach up to 2 metres/year. Once again, the authors recommend changes in water use and management.

5. Adaptation Plans and Tools

Along with research on climate and socioeconomic impacts on future water reservoirs and agricultural water demands, there is also a considerable number of publications regarding innovative approaches to adapt to the possible future scenarios of water scarcity. Some of the aforementioned research in the previous sections already provides suggestions on how to solve this problem within the areas studied by their authors. Nevertheless, there are other published studies in which the research goal involved directly the development of specific tools and plans designed to solve agricultural water scarcity within a given region. These studies are good examples of what the path followed by researchers and agricultural stakeholders should be, and also for decision-makers involved in the process of adaption to the future of agricultural water availability, namely the use of local- to micro-scale research approaches to water scarcity.

Starting by giving examples of adaptation efforts in Southern Europe, Stigter et al. [73] created a set of socioeconomic development (SED) scenarios for the central Algarve region in Southern Portugal. This was carried out through the engagement of farmers and stakeholders in the water sector through participatory workshops to develop better adaptation options, by integrating the perspective of those affected by socio-ecological changes. The SED scenarios were then combined with climate change and water recharge scenarios to assess possible impacts of climate change and socioeconomic development in an aquifer in central Algarve. The results revealed that under SED scenario 1, i.e., the decline of small farms, a large decrease in agricultural area and water demand will happen, while SED scenario 2, i.e., growth and modernisation of agriculture, proved to be unsustainable under climate change conditions if efficient adaptation measures are not adopted. Additionally, the temporal variability of the aquifer recharge showed a negative trend in the long-term period of 2070–2100. Thus, by considering SED scenarios with the direct input of those that could be affected by water scarcity in the future, Stigter et al. [73] found a dynamic interaction between climate change and socioeconomic factors in the Algarve region, information that could be helpful in the establishment of adaptation measures for this region. Also in Portugal, van der Laan et al. [74] evaluated how effective a series of sustainable land management (SLM) practices could be in reducing climate change impacts on the water availability and quality of the Montargil and Maranhão reservoirs in the Sorraia Basin, Central-west Portugal. Simulations of total phosphorus (TP) load in streams, reservoir volume, irrigation use, and water exploitation index (WEI) with the SWAT hydrological model for two mid-term (2041–2071) and long-term (2071–2100) periods, under the RCP4.5 and RCP8.5 scenarios, were carried out. The simulations showed that, under these climate change scenarios, the reservoir volume should decrease, and the TP load inflows should increase, thus worsening water quality. Nonetheless, with the implementation of the tested SLM practices, a decrease in TP load inflows and an increase in the reservoir volume can be achieved in the considered future climates, thereby demonstrating their effectiveness. At a wider European scale, Sordo-Ward et al. [75] also tested the effectiveness of different management practices in the mitigation of climate change impacts, but in water management instead of land management. The methodology followed consisted of calculations

of runoff for present and future periods under climate change, the estimation of water availability changes caused by changes in runoff and the evaluation of several water management adaptation measures with a Water Availability and Adaptation Policy Analysis (WAAPA) model, for six representative basins of southern Europe (Po, Struma/Strymon, Maritsa/Evros, Duero/Douro, Guadalquivir and Ebro). The adaptation measures included adjusting water allocation to agriculture, improving water storage capacity and increasing the efficiency of urban water use, chosen to maximise potential water availability. The assessment of these adaptation measures revealed that they can significantly increase water availability in some basins, such as the Ebro or the Struma/Strymon, whereas in other basins (e.g., Guadalquivir) an improvement of water availability cannot be achieved through the application of the tested measures, thus suggesting that reductions in irrigation water use will have to be made.

Besides testing alternative water and land management practices and developing improved climate and socioeconomic future scenarios, the creation of integrated modeling frameworks that combine hydrological, crop and atmospheric models is another crucial step into projecting more accurately the impacts of future climate and socioeconomic conditions not only on water reservoirs but also on crop water needs. The recent studies of Masia et al. [76] and Yalcin [77] are examples of research made in this field. To couple crop growth, soil water balance and irrigation practices to make integrated agricultural water assessments at local and regional scales, Masia et al. [76] combined crop and hydrological models into a single modeling platform entitled SIMETAW. The SIMETAW model can estimate crop water consumption, irrigation demand and scheduling, and was developed in two versions, one for local-scale and another for regional-scale simulations. To validate SIMETAW, its performance was tested in Mediterranean countries with calculations of climate change impacts on maize, wheat and wine grape water requirements in past (1976–2005) and future (2036–2065) periods under RCP4.5 and RCP8.5. The results presented an average water demand increase of approximately 13%, 16% and 10% in maize, wheat and grape production, respectively. Yalcin [77] went a step further and combined temperature and precipitation GCM projections with the SWAT hydrological model and the CROPWAT crop water/irrigation requirements model to assess the potential climate change impacts on irrigation water supply and demand in the Akmese Dam, Northwest Turkey. The climate projections were obtained through an ensemble of 24 GCMs, in which the simulations were made with the most recent radiative-forcing scenarios from IPCC, namely the Shared Socioeconomic Pathways (SSP) scenarios. By conducting this research for near-future (2025–2049), mid-future (2050–2074) and long-future (2075–2099) periods, the author concluded that due to gradual increases in mean annual maximum and minimum temperatures, and gradual decreases in mean annual total precipitation, mean annual inflow rates in the Akmese Dam are expected to decrease by up to approximately 8% and 26% during the long-future period under the SSP intermediate (SSP245) and severest (SSP585) scenarios, respectively. Seasonally, the decreases in mean annual inflows should be greater during autumn, owing to low rainfall concentrations during summer. Simultaneously, mean annual total irrigation requirements are projected to gradually increase by up to approximately 22% and 48% under SSP245 and SSP585, respectively. Therefore, Yalcin [77] states that approximately 22% and 39% of the total water demand and irrigation requirements, respectively, would not be able to be met at the end of the 21st century under SSP585. These results demonstrate how important the integration of different modeling platforms can be in determining, with higher accuracy, the sensitivity of water reservoirs to changes in temperature and precipitation.

Interestingly, the SWAT hydrological model has been frequently chosen by researchers when preparing integrated modeling platforms, as is the case of Bucak et al. [78], which has linked SWAT with a Support Vector Regression model and an ensemble of future climate data projections to assess future water availability in Lake Beyşehir (Southwest Turkey), or the case of Pulighe et al. [79], which forced a restructured version of the SWAT model, called SWAT+, with future climate projections data generated with two RCMs for a watershed in

Sardinia, Italy. SWAT has also been used in the assessment of possible alternative water and land use management, with the research of Rivas-Tabares et al. [80]. Besides SWAT-based integrated modelling platforms, a study by Collet et al. [81] proposes another innovative approach to the future water supply capacity problem. As a case study for their modeling approach, Collet et al. [81] aimed to determine whether the water resources of the Hérault River catchment (France), where a negative discharge trend had been observed since the 1960s, had been able to meet water demands in the region since that period. Their strategy consisted of combining a hydrological model with a dam management model to determine the availability of water resources, determine domestic water demand by calculating the annual ratio between water withdrawal and population number and determine agricultural water demand through the development of an irrigation management model based on the CROPWAT model. The resulting data were then used to calculate a water supply capacity index, able to assess if water demand in the catchment has been satisfied.

Considering the methodologies followed by each of the aforementioned studies, and the results and conclusions each was able to achieve, the development of integrated modeling frameworks and the calculation of monitoring indices has generated what are, essentially, decision–support systems (DSS). Studies such as Ronco et al. [82], Kourgialas et al. [83] and Domínguez et al. [84] show what can be the next stage for integrated modelling platforms, as farmers and stakeholders demand more precise information to undertake the best possible planning for their future activities. More specifically, Ronco et al. [82] developed a risk-assessment framework for the evaluation of potential water scarcity risk in the region of Puglia, southern Italy. Similarly to the SWAT-based research discussed previously, this framework consisted of the input of combined local hydro-meteorological and climate projection data, downscaled from projections generated by the COSMO-CLM RCM, coupled with the SWAT hydrological model, from which meteorological, hydrological and agricultural drought indicators were obtained. This integrated modeling approach was then developed into hazard maps, based on hazard classes defined according to a set of previously established equations. Analogously, vulnerability maps for the major crops in the studied region were also produced. With these maps, farmers in the Puglia region will be able to know which agricultural areas and crops are the most vulnerable to climate change. Then, knowing where vulnerability is mostly present, irrigation strategies can be planned accordingly, as a 2019 study by Kourgialas et al. [83] illustrates. In this study, the authors proposed to develop an optimal irrigation DSS for citrus and olive tree crops in the northwest of Crete (Greece). The system involves the use of hydrological data and field measurements as inputs to flow simulations with MIKE-SHE, a finite-difference hydrological model. After calibration and validation, the model was used to simulate soil moisture and pore water pressure within the studied area. The resulting data were subsequently used as guidance for the development of irrigation plans, which considered the needs of olive and citrus crops. By developing irrigation plans that aimed at maximising crop yields, while promoting water saving, the authors managed to project water use reductions of up to 36% for citrus trees and up to 41% for olive trees, during the dry season.

Existing DSS can also be adapted to alternative tasks related to agricultural activities. This is shown by Domínguez et al. [84], which had the goal of adapting for commercial use the MOPECO model, an irrigation model originally developed for scientific research purposes. Therefore, the authors had to simplify the irrigation scheduling module of the MOPECO model to give farmers and technicians a simple, but still effective, irrigation scheduling software aimed at improving irrigation efficiency and thus maximising the profitability of farms. The commercially adapted model was validated with the help of agricultural stakeholders in several Mediterranean water-scarce regions within Spain, Tunisia, and Lebanon. The model application led to an average yield increase of 10% in all three countries, as well as an average 16% decrease in water consumption. Moreover, this tool gathered interest from agricultural stakeholders and governmental entities, something that illustrates the commercial applicability of the integrated modelling platforms and individual models developed by the scientific community.

6. Discussion and Conclusions

This study aimed to review the most relevant published studies about the impacts of climate change on water availability for the Mediterranean agricultural sector, to give a global view of the future water supplies in the region and the most common and effective adaptation measures suggested by the scientific community. For this purpose, a total of 2437 records obtained from the Scopus and WoS databases were subjected to a PRISMA2020 guideline methodology, which included report exclusion following several criteria and an initial report screening. The application of the established methodology resulted in a final number of 44 reports. It is worth mentioning that the search equations used in the Scopus and WoS databases, which had "south* europe" and "mediterranean" as their geographical search keywords, may have failed to detect some published studies dedicated to smaller, local areas within the Mediterranean countries, and thus some relevant research on the topic of future water availability in the Mediterranean Basin may have been left out of this review. Moreover, a number of 44 reviewed studies could also be considered small for a Mediterranean-scale review. Nevertheless, the temporal and spatial scope of these 44 studies should be considered, since overall, these studies have a timespan from the late 1980s until early 2024 and a geographical span covering almost all the Mediterranean-surrounding countries. Additionally, the innovations in methodologies and datasets that occurred throughout the reviewed timespan can be seen from study to study, as well as breakthroughs in results, which allow a Mediterranean-scale view of the trends of variables such as precipitation, temperature, reserve water volumes, and crop irrigation needs, over the last 35 years. Hence, it seems safe to assume that the 44 reviewed studies are representative of all the research made on future water availability for the Mediterranean agricultural sector during the 35 years prior to the present review.

A bibliometric analysis of the title and keywords of the gathered reports showed that the study areas targeted by most of the research on future water availability for the agricultural sector are concentrated in Spain, Italy and Portugal. Moreover, the most studied crops appear to be vineyards and cereals (i.e., wheat, maize and barley), followed by olive trees, citrus trees and tomatoes. These findings were expected, considering that the aforementioned crops are the most cultivated in the Mediterranean Basin.

If the projections of all the reviewed studies are merged, a general perspective of the future climate and socioeconomic scenarios' impact on water availability for the entire Mediterranean Basin can be established, for the main IPCC scenarios and periods studied. The IPCC scenarios most considered by the reviewed studies are the RCP4.5 and RCP8.5, which appear in studies from Spain, Portugal, Turkey, Tunisia and Morocco. Second to the RCP scenarios are the IPCC A1B and A2 scenarios, which only appear in studies from Spain, Portugal and Italy, and therefore only allow an analysis of the Western European part of the Mediterranean Basin.

Starting with the IPCC A1B scenario, which is an emissions scenario that represents a future of social convergence, technological development and rapid global economic growth based on a balanced use of all energy sources [85], a general analysis of the results from the Iberian Peninsula (i.e., Portugal and Spain) and Northern Italy suggests that water resources and irrigation demand in these regions should gradually decrease and increase, respectively, throughout the century. In the Iberian Peninsula alone, water resources could decrease around 20% and irrigation demand could increase 10% during mid-21st century. Nevertheless, some areas could see an increase in maximum peak flow and surface runoff, as seasonal precipitation variability and winter precipitation are projected to increase over several locations. In the IPCC A2 scenario, which represents a future of regionally-oriented economic development, a continuously increasing population, and high CO_2 emissions [85], the decrease in water resources in eastern Spain is expected to be even higher, with projections indicating a 15% to 35% decrease during spring and summer in 2041–2060 in the Ebro Basin and a 40% to 50% decrease during 2070–2100 in the Júcar Basin.

Moving to the IPCC RCP4.5 scenario, which describes a future where emissions peak around 2040 and then start to decline [86], the results of the reviewed studies point

towards a 40% decrease in water resources in central Spain and a 18% decrease in annual flow rates in northern Portugal throughout the 21st century. Meanwhile, research on Western Turkey's water reserves is contradictory, as Okkan et al. [68] indicate that reservoir inflows should decrease by 15% until the mid-21st century, and on the contrary Gorguner et al. [69] indicate that inflows should increase by around 20% in the same period. However, Gorguner et al. estimate that the inflow increases become smaller throughout the century. In Northern Tunisia, the research of Allani et al. [71] concluded that reservoir inflow should decrease up to 37% during 2061–2080. In the IPCC RCP8.5 scenario, which describes a future where emissions continuously increase throughout the 21st century [86], the same studies predicted a 47% decrease in water resources in Central Spain and a 28% to 30% decrease in annual flow rates in Northern Portugal throughout the 21st century. Simulations by Rocha et al. [63] also indicate that, during 2070–2100, reservoir inflows in Southern Portugal could decrease by 7% to 19%, and irrigation demand could increase by 31%. Moreover, it is estimated that water transfers from the Tagus Basin (Central Spain) to the Segura Basin (Southeast Spain) could decrease by 70% to 79% in both RCP4.5 and RCP8.5 scenarios, thus leading to a decrease in Southeastern Spain's water resources. As for Western Turkey's water reserves, reservoir inflows should decrease by 21% until the mid-21st century. Similarly to RCP4.5, reservoir inflows in Northern Tunisia should also decrease up to 37% during 2061–2080.

Overall, the reviewed studies showed that between the mid and last decades of the 21st century, and under the projected future climate conditions associated with different future socioeconomic scenarios, most of the Mediterranean Basin will be exposed and vulnerable to increasing temperatures and drying trends, which will cause a decrease in reservoir inflows and aquifer recharge (and thus a decrease in water reserves), increasing runoff losses, higher evapotranspiration and irrigation demand by some crops, as well as reductions in water quality. When comparing the RCP-based projections with the A1B and A2-based projections for the Iberian Peninsula, they appear to be similar regarding the signal of the trend and the magnitude of the relative anomaly. Nevertheless, despite several projections being in agreement, it is important to mention that the chosen climate models play a relevant role in the hydrological simulations, as is proven by the research of Rocha et al. [63], which concluded that, for the same RCP4.5 scenario and 2070–2100 period, SWAT hydrological simulations with RACMO22E climate data estimated a 4% to 8% decrease in reservoir inflows, while the same simulations with RCA4 climate data estimated a 42% to 49% increase in reservoir inflows.

The expected temperature increases and precipitation decreases that lead to the projected reductions in water reserves could make the Mediterranean climate more arid, and along with the projected increases in irrigation water demand and reservoir depletion, this could make olive trees and grapevines more exposed to drought conditions, which could lead to yield reductions and could affect wine and olive quality [87,88]. In a worst-case scenario, the cultivation of olive trees and grapevines could even become unsuitable in certain parts of the Mediterranean Basin, with the suitable climate conditions for their cultivation shifting to northern regions [89–91].

Regarding the methodologies and research goals of each study, during the review, it was found that the most recent studies have given particular attention to the development of integrated modeling frameworks, which combine global and regional atmospheric circulation models with hydrological and crop models. This innovative modeling approach can help reduce agricultural water losses and consumption while simultaneously maintaining, or even improving, current crop yields, to respond to the growing global food demand. The attention given by the scientific community to integrated modeling frameworks has been promoted by the projected impacts of climate change and socioeconomic development changes in the future water reserves which, according to the reviewed studies, may not be sufficient to meet the growing water requirements of the agricultural sector. Given this possibility, the need to establish more effective agricultural water-use planning and adaptation strategies arises. Therefore, several of the reviewed studies recom-

mended adaption measures, such as simulations of future water availability with the use of socioeconomic development (SED) scenarios co-created with farmers and agricultural stakeholders, sustainable water use and land-management practices adequate to the local basin's characteristics, use of risk assessment frameworks to accurately determine risks for local water reserves and crops, and the development/adaptation of DSS to a wider (and likely commercial) use.

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