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Assessing the Effectiveness of the WFD as a Tool to Address Different Levels of Water Scarcity Based on Two Case Studies of the Mediterranean Region

Stella Apostolaki ^{1,2,3,*} , Ebum Akinsete ^{1,2,4}, Stella Tsani ^{1,2,5}, Phoebe Koundouri ^{1,5} , Nikittas Pittis ⁶ and Eleftherios Levantis ^{1,2}

¹ ATHENA Research and Innovation Center - EIT climate KIC Hub, Greece, 6 Artemidos str., Paradeissos Amaroussion, GR 15125 Athens, Greece; ebum.akinsete@icre8.eu (E.A.); stella.tsani@icre8.eu (S.T.); pkoundouri@aueb.gr (P.K.); elan@otenet.gr (E.L.)

² International Center for Research on the Environment and the Economy (ICRE8), 3 Romanou Melodou str., Paradeissos Amaroussion, GR 15125 Athens, Greece

³ Department of Science and Mathematics, Deree - the American College of Greece, 6 Gravias str., Aghia Paraskevi, GR-153 42 Athens, Greece

⁴ School of Applied Social Studies, Robert Gordon University, Aberdeen AB10 7QB, UK

⁵ Athens University of Economics and Business, School of Economics & ReSEES Laboratory, 76 Patisision Str., GR10434 Athens, Greece

⁶ Department of Banking and Financial Management, University of Piraeus, M. Karao & A. Dimitriou St., GR18534 Piraeus, Greece; npittis@webmail.unipi.gr

* Correspondence: stella.apostolaki@icre8.eu; Tel.: +30-210-610-5244

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Abstract: Despite being a natural phenomenon, water scarcity is, to a great extent, human-induced, particularly affected by climate change and by the increased water resources vulnerability. The Water Framework Directive (WFD), an ‘umbrella’ directive that aims to provide holistic approaches to the management of water resources and is supported by a number of Communication documents on water scarcity, requires for prompt responses to ensure ‘healthy’ water bodies of good ecological status. The current paper presents a multidisciplinary approach, developed and engaged within the Globaqua Project, to provide an assessment of the main challenges towards addressing water scarcity with emphasis on the climate change projections, in two Mediterranean regions. The current paper attempts to critically assess the effectiveness of the WFD as a tool to address water scarcity and increase sustainability in resource use. Criticism lies on the fact that the WFD does not directly refer to it, still, water scarcity is recognized as a factor that increases stress on water resources and deteriorates their status. In addition, the Program of Measures (PoMs) within the WFD clearly contribute to reducing vulnerability of water resources and to ensure current and future water use, also under the impact of the projected climate change.

Keywords: water scarcity; sustainable resource management; integrated water management; Program of Measures; climate change; multidisciplinary approach

1. Introduction

Water scarcity, according to the Human Development Report of the United Nations [1] is recognized not only as a physical phenomenon but also as a result of unbalanced power relations, poverty and inequality. This realization lies on the fact that water availability is often linked to unequal share and exploitation of natural water resources as well as to social injustice. Furthermore, physical water scarcity, although it forms a natural phenomenon, it may be i) demand-driven (water stress) that

equals the amount of water withdrawn from natural resources [2–5], ii) population-driven (water shortage) related to the populations having access or putting stress on the water resources [5,6] and iii) climate change driven, modifying the spatiotemporal distribution, intensity, frequency of physical parameters such as precipitation, temperature, humidity, wind speed, evapotranspiration, ocean currents, and wind circulation [6–8]. Studies have shown an increase in the population under water stress or under water scarcity, as a result of all the aforementioned parameters [9,10].

The EU Water Framework Directive (WFD) [11], which was introduced to tackle water management issues in a holistic way, addresses the issue of water scarcity indirectly, through the requirement to ensure good ecological and chemical status of all surface, groundwater and coastal water bodies. Moreover, combating drought and water scarcity, although comprise priorities in water management, they are not clearly included in the goals of the WFD. To cover this gap, a series of Communication Documents [12,13] were issued by the European Commission (EC), complementary to the WFD. Ref. [13] forms part of the Blue Print for Safeguarding European Waters [14] that stresses the necessity to combat water scarcity, particularly relevant under the climate change scenarios. The WFD calls for informed Program of Measures (PoMs) that also target the human induced water scarcity, linked to water abstraction and use, as well as to climate change. Measures to address water scarcity or responses to the issues at hand, particularly relevant for the most vulnerable drought-prone regions would have to go beyond traditional approaches so as to address future water scarcity. The traditional crisis management approach, has resulted in significant failures, which under the pressure of the changing climatic conditions impose additional stress into the water resources [15]. The WFD provides a robust framework for informed measures within the River Basin Management Plants (RBMPs), within which risk and impact assessment take into account uncertainty caused by climate change [16]. Any potential failures can be, therefore, attributed to lack of funding and of robust implementation rather than to measures that are inherently weak.

The current paper aims to assess the effectiveness of the WFD as a tool for reducing vulnerability of water resources based on the assessment of water scarcity and climate change conditions, as well as on the responses adopted as part of the WFD requirement in two Mediterranean river basins. The selected river basins face different levels of water scarcity, ranging from high levels in Souss Massa in Morocco, to seasonal water scarcity in Evrotas in Greece. The two cases examined here form part of the Globaqua CP FP7-ENV.2013.6.2-1 Project Case Studies. The multidisciplinary methodological framework that was followed, is based on well-defined processes formulated by the project partners; it includes the assessment of background conditions in relation to physical water scarcity, mapping of the responses targeting water scarcity, and future projections under climate change and socio-economic scenarios.

2. Methodology

The current paper presents an overview of the processes and outcomes, followed in the Globaqua project in relation to the present and projected climatic and water availability conditions that affect the level of water scarcity in 2 areas facing similar yet, diverse water stress issues. The methodological framework used in the Globaqua project starts with the characterisation of the regions that emphasises on the water availability and scarcity issues, based on data gathered from the Case Study Leaders of the Globaqua project and the project partners through the local utilities in the selected Case Studies. Literature sources were also used in support of the information gathered at source. Analysis of the Program of Measures (PoMs) that are aimed to address water scarcity as response to the WFD implementation process, follows. The next step is the assessment of a climate change uncertainty to predict future changes and the related impacts on water scarcity (Figure 1). Along this line 12 high-resolution Regional Climate Model (RCM) simulations generated within the Coordinated Regional Downscaling Experiment (CORDEX) activities, program sponsored by the World Climate Research Program [17] have been utilised. Five Coupled Model Intercomparison Projects of the 5th Phase (CMIP5) General Circulation Models (GCMs) have been downscaled over Europe, in different

combinations, by four RCMs at about 12 km resolution and under two Representative Concentration Pathways (RCPs) (−45 and 85).

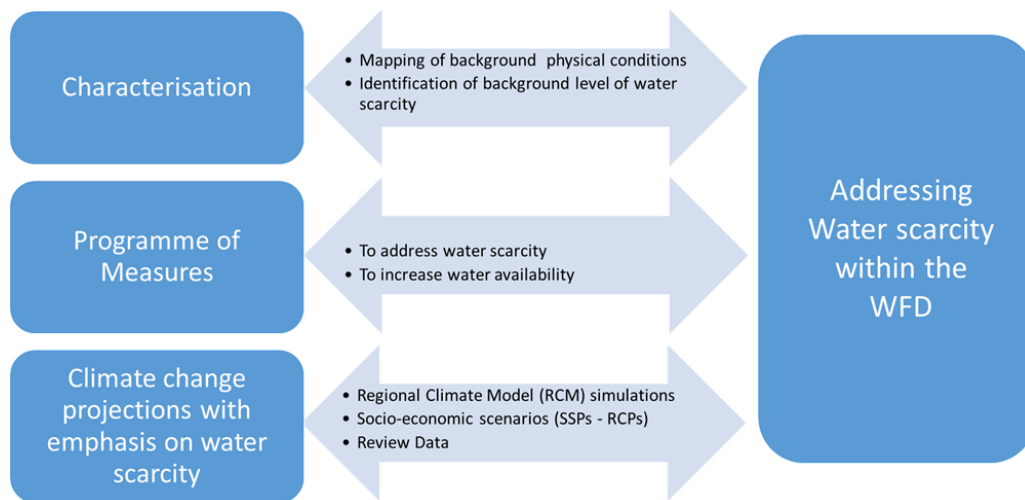


Figure 1. Schematization of the process followed in Globaqua. WFD: Water Framework Directive.

The main focus was placed on assessing future climate change for the period 2035–2065, using as a reference period the years 1981–2010. Other subsequent periods used are 2011–2040; 2041–2070, 2071–2100. The two main variables taken into account in order to assess future changes in climate, are temperature and precipitation, while the total runoff was derived directly from the RCM output, as it comprises an important variable in water balance and availability that defines the level of water scarcity.

On top of climate projections scenarios, socio-economic scenarios were developed within Globaqua. A baseline scenario that describes the changes from the current state to the future (2050) was developed. The baseline scenario identified a wide gap between the current and the desired state of water resources and the need for improving the program or package of measures to close this gap (Figure 2). Lack of improved measures is expected to deteriorate the conditions.

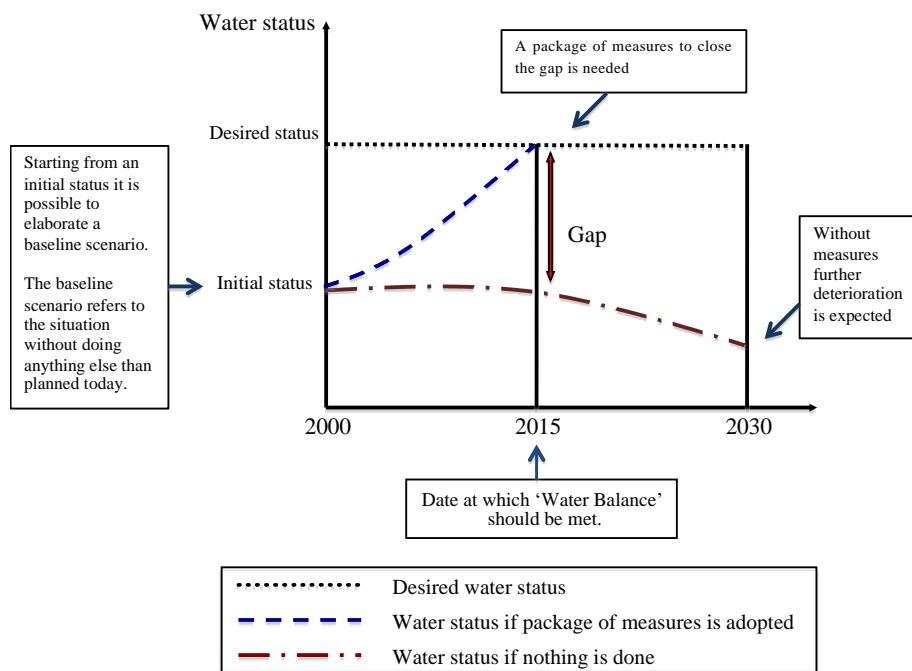


Figure 2. Development of a baseline scenario for assessing future state [18].

The socio-economic scenarios tested within the Globaqua project followed the IPCC prototype Scenarios ‘Shared Socio-Economic Pathways’ (SSPs) and the ‘Representative Concentration Pathways’ (RCPs) portraying different policy futures [19–22]. Two out of the four scenarios, the environmental friendly scenario ‘Sustainable’ and the economy friendly ‘Myopic’ scenario, are downscaled for the case of Evrotas to further identify potential changes in the water availability and water scarcity level. The former scenario prioritises sustainable development with reduced levels of greenhouse gases and integrated long-term water resource management, while the latter portrays faster than the average economic growth for the first 25 years that allows investment and growth in human capital, promotes technological advances that enhance adaptation to climate change but no action on mitigation, thus increased CO₂ emissions and projected global warming [23]. The downscaling of the scenarios to enable the impact and state valuation at river basin level, was materialized in relevant workshops and interview sections by experts and local stakeholders in a dual effort of gathering information and raising awareness, underlining also the central role of stakeholder involvement in planning and decision making in accordance to the WFD. The stakeholders, whom included end-water users, within the whole spectrum of water related and economic activities (local and regional authorities, farming associations, tourist associations, citizens) were asked to identify the weight of different parameters, ecosystem and social attributes at river basin level.

3. Results

3.1. Evrotas, Greece—A Case of Seasonal Water Scarcity and Seasonal Flooding

3.1.1. Physical Characterization of the Region

The river basin of Evrotas covers a catchment area of 2240 km² in the South-East of Peloponnese (Figure 3), which comprises one out of the fourteen river basin districts within the Greek territory, and serves a population of 68,400 (according the latest official census, 2011). The catchment drains a mid-altitude region of 150–600 m with numerous small intermittent streams discharging into the main river body. The climate is typical temperate Mediterranean with high temperature seasonal fluctuation, average summer temperature 26.2 °C and average winter temperature 9.1 °C and remarkable annual variations in precipitation [24]. Average precipitation in the river basin is 902.7 mm, evaporation level is 497.1 mm, environmental demand is 205.0 mm and returned water 12.3 mm [25].

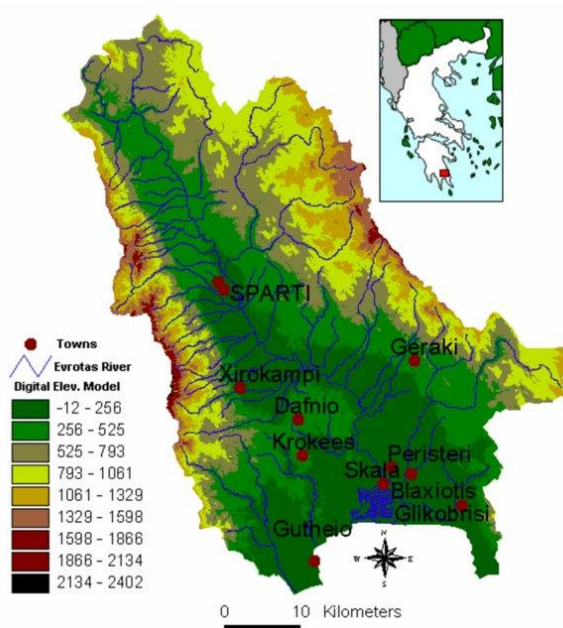


Figure 3. The Evrotas river basin [26].

The Evrotas river basin appears to have ample resources and relatively stable water needs across the various economic sectors, ensuring a satisfactory water balance at least in the mid-term. Agriculture accounts for 89% of the water use in the river basin, using 330 mil. m³ of water annually, while total water use accounts for 373 mil. m³. Groundwater pollution in the area is also linked to agricultural and food processing activities, and the increased levels of Fe, Mn, SO₄, as a result of natural infiltration processes. The overall annual surface loads from diffuse and point sources, as well as atmospheric depositions are 2773.5 tons/year BOD, 701.9 tons/year N and 52 tons/year P. During the summer period, the relevant pollutant loads are 935.5 tons/year BOD, 230.1 tons/year N and 16.8 tons/year P respectively. The over-exploitation of water resources for agricultural use (agriculture comprising the biggest economic activity in the region and the highest water consumer), in combination with a range on varying factors such as point and diffuse sources of pollution and the climate change effects are disturbing the supply-demand balance. Furthermore, they result in disturbances of the surface and groundwater resources, desiccation of large parts of the hydrological network, artificial intermittence of the catchment streams [27,28], and drought incidents [29].

As a response, the Special Secretariat of Water of the Ministry of Environment Energy and Climate Change drafted a drought and water scarcity management plan for the Peloponnese River Basin Districts within the implementation of the Water Framework Directive 2000/60/EC in Greece [25].

3.1.2. Measures as a Response to Water Availability Issues

The Program of Measures at the Evrotas river basin includes a wide range of regulatory interventions to address the principles of the WFD with emphasis on monitoring and protection of surface water bodies, groundwater, drinking water, bathing waters, biodiversity, reduce pollutant loads, eliminate risks, provide for wastewater treatment. Technical measures related to pollution emission control (establishment of protection zones around existing active and inactive sinkholes; enhancement of existing water supply network; incentives to promote organic farming; motivation for promotion of tertiary wastewater treatment where applied; protection measures for geothermal hot springs; groundwater quality monitoring for salinization), abstraction control (annual quantitative and qualitative controls of groundwater bodies; control of abstraction projects), educational and raising awareness measures to enhance sustainable use of natural resources, recreation and restoration of wetland areas and of parts of the river with emphasis on biodiversity, and economic measures (strengthening the credibility of estimation of full cost of water, including environmental and resource costs). Additional technical measures include the foreseen reconstruction and restoration of wetlands areas, abstractions control, demand management measures, measures of efficiency and reuse, construction projects, such as desalination plants, rehabilitation projects, artificial recharge of the groundwater aquifer, and sediment controls [30]. Although the regulatory measures are fully implementable and in place, some of the technical measures, such as restoration measures require more effort. The reason is related to the cost of the technical measures and not to their efficiency.

3.1.3. Climate Change Projections on Water Scarcity

Climate projections following 12 individual simulations undertaken within the framework of the Globaqua project, foresee an increase in temperature in the Evrotas river basin of about 2°–3° during the period 2036–2065. The same simulations foresee decrease in precipitation by 10–20% over the entire Evrotas catchment. Analysis of the precipitation rates seems to reach the same results. These results are also in line with an assessment of past ‘historical’ scenarios for the years 1900, 1960, and 1980, which shows a clear decrease in the discharge in the river in comparison to the previous century [31]. Even with a remarkable spread in the magnitude of change, all 12 individual simulations show a prominent decrease in precipitation for the Evrotas basin, which seem to be followed by remarkable decrease in the total runoff in the future that may reach even 30%, if the issue is not adequately dealt with. However, these results are valid under the scenario RCP 8.5 that shows a pathway of high greenhouse gas emissions, linked to high climate change [32], while the scenario RCP 4.5, a stabilization scenario

that assumes that climate policies, are invoked to achieve the goal of limiting emissions and radiative forcing [33], does not demonstrate significant changes throughout the catchment. The ensemble shows, therefore, at least for RCP 8.5, clear climate change by the end of the 21st century associated with increase in temperature and decrease in precipitation and annual runoff that impose high stress on the water resources and increased water scarcity and drought. These results are combined with the downscaling of the socio-economic scenarios that sees an increase in urbanization and in the irrigated land, while intensive crop production will decrease due to turn towards organic crops. Despite their differences, both scenarios, the ‘sustainable’ and the ‘myopic’ foresee changes in the water resources and future Program of Measures that should focus primarily on the protection of ecosystems and water resources, on revised water pricing schemes to fully incorporate environmental and resource cost, and on securing water supply that covers the demand. A different hydrological analysis of the Evrotas river basin, where two similar socio-economic scenarios, ‘sustainable’ and ‘worst-case’ were assessed for 2050 and for the end of the century, shows changes in the intensity of rainfall events, increase in evapotranspiration over summer and extensive spring dry periods and all year dry periods also linked with increased water scarcity [34].

3.2. Souss Massa, Morocco—A Case of Severe Water Scarcity

3.2.1. Physical Characterization of the Region

The Souss-Massa river basin is located in southwestern Morocco, covers an area of 27,000 km² (Figure 4), serves a population of 2.33 million (54% rural and 46% urban) and comprises one of the country’s most important hydrological catchments, with high elevation differences ranging from 0 m at the Atlantic Ocean to 4168 m at the Toubkal peak in the High Atlas Mountains. The watershed of the study area comprises 25% of plains and 75% of mountains. It is located within four geological features that regulate the climate, the Atlantic Ocean to the west, the High-Atlas Mountains to the north, the Anti-Atlas Mountains to the east and Sahara to the south. Cold fronts are blocked north by the High Atlas, while ocean breeze forms mild climatic conditions in the coastal zone [35].

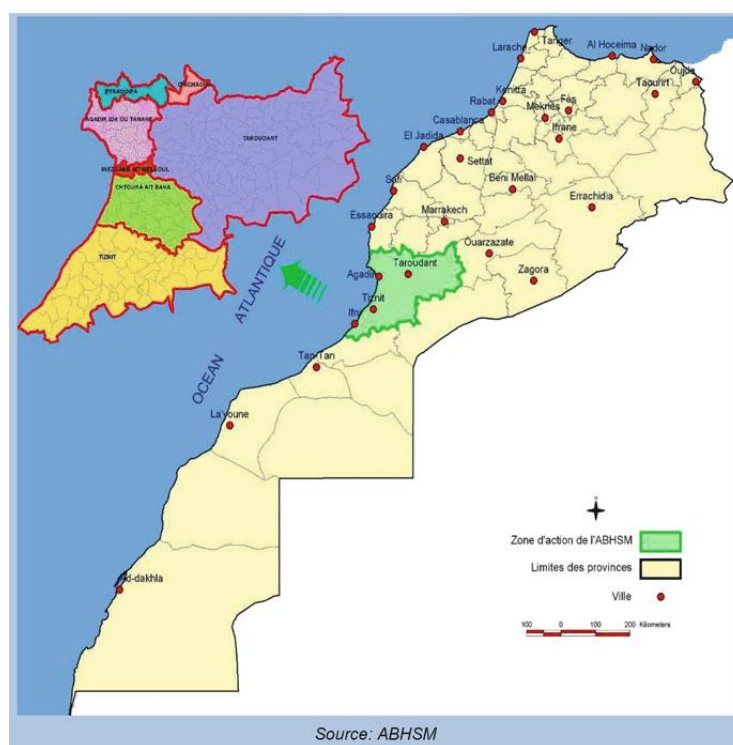


Figure 4. The Souss-Massa river basin [36].

The climate in the region is semi-arid to arid, characterized by high fluctuation in humidity between the mountainous region and the plains and by large spatial and temporal variability in precipitation from 300 to 600 mm in the High Atlas, to approximately 200 mm/yr in the plain, further influenced by climate change [37,38]. Climate in the region is affected by spatial characteristics, the distance from the Atlantic, and the anticyclone of the Azores, the frequency and intensity of which has increased significantly and are expected to further increase affecting temperature, precipitation and weather extremes [39], phenomenon which is also linked with the North Atlantic oscillation [35,40]. The average evaporation potential ranges from 1400 mm in the mountains with proximity to the Atlantic coast to 2000 mm in the plain. The hydrological regime of two main rivers, Souss and Massa, is characterized by strong seasonal and interannual irregularity, with the maximum inflow occurring during January, February and March, and the minimum inflow in August. The entire hydrologic basin shows a discharge shortfall, with 20% decrease in rainfall during the last 30 years. The overall balance between water supply and demand is negative due to the increasing demand to cover domestic and agricultural needs, and the considerable degradation of the water resources due to pollution. The groundwater aquifer is affected by overabstraction; the drop of the water table averages 3 to 5 m annually. Overall, the Souss-Massa basin is facing considerable water scarcity due to the limited precipitation level, the constantly increasing water demand to cover the intensive agriculture that uses 92.33% of the natural water resources and comprises the main economic activity in the region and the increase in tourist activity [41]. At the same time the groundwater abstractions to cover primarily the agricultural water demand, result in severe depletion of the groundwater aquifer associated with saltwater intrusion and groundwater salinization [36]. Consequently, the Souss-Massa basin is facing increasing water shortages. The estimated water shortage in 1990 appeared to be 60 Mm³ per year [42] while the annual water deficit in 2005 has reached 260 Mm³ [43], and 283 Mm³ in 2007 [36].

3.2.2. Measures as a Response to Water Availability Issues

As a response to water scarcity at Souss Massa and in line with the WFD, a Program of Measures is in place aiming to resolve issues related to covering the water demand and eliminating risk of flooding and droughts, as well as resolving water governance issues. The PoMs focuses on the agricultural sector and on enhancing the hydrogeomorphology of the region to cover the increasing water demand. The technical measures addressing the agricultural pressures focus on reduction/modification of the fertilizer and pesticide application, on supporting low-input farming (organic farming), monitoring of hydrogeomorphological parameters aiming to support changes in farming practices, improved irrigation efficiency (more than 90% of farmers have turned from surface irrigation to drip irrigation) [44] and multi-objective measures such as crop rotation, creation of enhanced buffer zones/wetlands, or floodplain management. Economic instruments are in place to support the technical measures and include pricing specifications for irrigators, land cover compensation, taxation for the application of fertilizers and pesticides. The legal instruments aim to support the implementation of existing legislation, to enhance controls, support institutional change, introduce codes of agricultural practice, enable zoning (e.g., designating land use based on GIS maps) for improved land use planning, introduce specific action plans and programs. In addition, emphasis is paid on enabling environmental permits, licensing, raising public awareness and enhance knowledge on farming practices [36].

The hydrogeomorphological measures are aiming at (i) river restoration works (restoration of banks and degraded bed structure, lowering of river banks, reconnection of meander bends or side arms, remeandering of formerly straightened water courses, restoration of transitional and/or coastal waters, operational modifications, reduction or modification of dredging hydropeaking, sediment/debris management, removal of structures: weirs, barriers, bank reinforcement), at (ii) enhancing river flow performance to ensure uninterrupted flow and flood protection (bypass channels inundation of flood plains, setting minimum ecological flow requirements, construction of retention basin), at (iii) conserving biodiversity (habitat restoration, building spawning and breeding areas, fish ladders) [36], and at (iv) supporting water supply through a series of measures, such as the

construction of numerous dams to mobilize 1.7 billion m³/year, transfer of water volumes from the North basin to the South (800 Mm³/year), use of unconventional water resources (wastewater treatment and reuse, rainwater harvesting, and seawater desalination) [44]. Hydrogeomorphological measures are not fully implemented due to high cost. Still some of the technical measures, such as the turn from flood irrigation to drip irrigation, have demonstrable positive results that equal 90% of reduction in water consumption.

3.2.3. Climate Change Projections on Water Scarcity

Future projections on climate in the river basin are made on the basis of the demand–supply relation, information from literature and current measurements on demand, supply, precipitation and temperature. The current analysis identified decrease in precipitation levels and increase in temperature for the end of the 21st century. The industrial water use is also expected to increase by about 31.12 %, based on data from 2009 to 2012, while the overall water uses will follow a stable annual increase of about 9%. To cover the demand, the supply will continue to depend on the abstraction from the groundwater aquifer resulting at overexploitation of the resource, possibly linked to sea water intrusion and salinization. The overall water balance is expected to face a deficit of –617 Mm³ in 2030 and of –657 Mm³ in 2050 under conditions of no change in climate and of –811 Mm³ in 2030 and –1003 Mm³ in 2050 under climate change conditions [45]. An interesting finding from the same study is the projected groundwater deficit, which is 155.8 Mm³ and 50 Mm³ for 2030 and 2050 respectively under conditions of zero climate change, and 188.6 Mm³ and 119.5 Mm³ for the same years under climate change conditions. Other pressures that are expected to rise are related to diffuse pollution (nutrient pollution) from the agricultural activity [45]. A different study [46], using different prediction models, estimated a temperature increase of 2 °C for the period 2030–2050, and up to 4 °C during 2090–2100 under the RCP8.5 scenario, associated with precipitation decrease, that reaches up to –53% at high altitudes, by the end of the 21st century.

4. Discussion

The multidisciplinary analysis undertaken as part of the currently presented work, attempted to identify current and future water scarcity stresses in two Mediterranean river basins, facing similar yet different levels of water scarcity, from high in Souss-Massa to moderate seasonal in Evrotas, which however, affect water availability and have significant impacts in the economic sector. Both examined Mediterranean case studies face seasonal increased water stress, due to the prolonged summer dry periods, the high agricultural activity with agricultural water use comprising the biggest water consumer in both areas, and the tourist influx in summer months, a significant stress particularly in the Evrotas region. The presented framework entails analysis of background conditions, responses/measures to tackle water stress, and climate projections using climatic models and socio-economic scenarios that foresee an overall increase of the water scarcity levels, in the mid to end of the 21st century. The reasons behind the expected water stress are related to temperature increase, precipitation decrease and the socioeconomic changes in the Mediterranean region. The foreseen changes are expected to intensify further due to the rising rate of urbanization, the increased water demand for crop irrigation to cover the needs of the increasing population, particularly true for the Moroccan case, and the projected climate change. Climate projections identify further intensification of seasonal stress in the water resources. There is, therefore, prioritization of the responses regarding water saving in the agricultural sector; irrigation has been identified as the biggest water consumer in both regions. Efforts focus on control of the water scarcity and drought, factors that clearly influence the physicochemical and the ecological status of water bodies [47] and form central issues for the well-being of water resources and human societies. The means to address and eliminate water scarcity, according to Article 11 of the WFD, is the formation of informed responses via the Program of Measures [12], as a first step towards the River Basin Management Plans, in accordance to Article 13 of the WFD [12]. The timeline for the PoMs includes 3 cycles, 2009–2014, 2015–2021, and 2021–2027. Under the pressure

of economic constraints in Europe, the end of the 1st cycle of implementation finds most EU member states in search for alternative sources of funding and cost-effective solutions. As a general criticism on the PoMs one could claim that measures are not always adequately linked to water bodies and lack clarity on the economic pressures they address. Criticism on the applicability and efficacy of measures, however, should also take into consideration the fact that we are currently half-way through the 2nd cycle of PoMs implementation. The foreseen measures although targeted and informed have not been fully implemented and would have to be judged accordingly, also under the economic conditions and constraints in the Mediterranean region.

In the currently described Case Studies the related PoMs classify responses as technical, socioeconomic and legislative measures, all together addressing physicochemical, hydrogeomorphological, and societal issues. Central measures in the described PoMs examined within Globaqua, in the Evrotas and the Souss-Massa river basins, are those aimed to address the pressures linked with the agricultural water use, as the main water consumer, stressor and driver behind the increasing water stress. A more elaborate classification of measures could be based on responses that are aimed at 'achieving the environmental objectives', 'satisfying water demand', 'addressing risk management to reduce floods and droughts' and 'at informing governance'. It is, however, difficult to estimate the level of achievement of environmental and water demand objectives under the stress of climate change conditions. In addition, the flood and drought reduction objectives should be further stressed and linked to awareness raising and governance issues. Awareness raising in combination with economic measures/initiatives seem to have increased water saving in the agricultural sector, with obvious positive impact on reducing water scarcity, as agricultural water demand accounts for the massive 92.33% of natural water resources in Souss-Massa and over 80% of water use in Evrotas. In Souss-Massa, a river basin facing severe water scarcity issues, modernization of irrigation takes a significant percentage of the budget of the measures; drip irrigation has replaced the traditional flood irrigation in 90% of farms, providing an instant relief on the scarce water resources and clearly contributing towards achieving the WFD objectives. An overview of the PoMs selected in the 2 case study regions and their level of applicability and future potential are summarized in Table 1.

Table 1. Instruments to address water scarcity and level of applicability [31,36].

	INSTRUMENTS	LEVEL OF APPLICABILITY
	Regulatory and Legal Instruments	
	Monitoring and protection of water bodies, protection of biodiversity, reduction of pollutant loads, elimination of risks, regulation of wastewater treatment.	High level of applicability through national legislation
	Technical Measures	
EVROTAS	Establishment of protection zones around sinkholes; Enhancement of existing water supply network; Support of organic farming; Support tertiary wastewater treatment; Protection of geothermal hot springs; Groundwater quality monitoring; Prioritization on full cost recovery	Ongoing processes
	Hydrogeomorphological Measures	
	Foreseen reconstruction and restoration of wetlands areas; Artificial recharge of the groundwater aquifer; Demand management measures; Measures of efficiency and reuse; Construction projects such as desalination plants; Extensive abstractions control; Rehabilitation projects; Sediment control	Long-run measures - Financial constraints affect applicability

Table 1. Cont.

	INSTRUMENTS	LEVEL OF APPLICABILITY
SOUSS MASSA	Regulatory and legal Instruments	
	Enhance controls; Support institutional change; Introduce codes of agricultural practice; Enable zoning (e.g. designating land use based on GIS maps) for improved land use planning; Introduce specific action plans and programs; Environmental permits and licensing	Applicability through national legislation – ongoing progress
	Technical Measures	
	Reduction of the fertilizer and pesticide application; Support of organic farming; Monitoring of hydrogeomorphological parameters; Improved irrigation efficiency; Creation of enhanced buffer zones/wetlands or floodplain management; Codes of agricultural practice; Zoning; Pricing instruments in irrigation; Land cover compensation	High level of applicability of interventions in the agricultural sector.
	Hydrogeomorphological Measures	
	Restoration of bank and degraded bed structure; Lowering of river banks; Reconnection of meander bends or side arms and re-meandering of formerly straightened water courses; Restoration of transitional and/or coastal water through operational modifications; Modification of dredging hydropeaking; Sediment/debris management; Removal of structures: weirs, barriers, bank reinforcement; Bypass channels inundation of flood plains; Construction of retention basin; Habitat restoration (building spawning and breeding areas, fish ladders); Dam construction; Wastewater treatment; Measures to enable water reuse (rainwater harvesting); Seawater desalination	Long-run measures - Financial constraints affect applicability

The measures outlined for each case study, as part of the respective PoMs, cover a broad range of interventions that can adequately address water scarcity at present conditions. The legal instruments can have a more direct implementation and effect depending on enforcement; the level of efficiency being moderate to high in both case studies. Technical and hydrogeomorphological measures present different applicability levels that are related to financial constraints. The technical measures aiming at improving water efficiency of agricultural practices and at supporting organic farming, demonstrate high applicability and efficiency levels. In the Moroccan case in particular, adaptation to new water saving practices that relieves significant stress from the depleted surface and groundwater resources, demonstrates remarkable results. The hydrogeomorphological measures comprise a big challenge for both case studies as the financial and time investment is very high. Those measures are applicable in the long run and demonstrate moderate levels of applicability and efficiency due to financial constraints. The WFD alongside with the EC Communication and Guidance Documents could, therefore, be characterized as adequate in covering the requirement for water resource management through informed measures. The WFD requirement for good ecological status of all water bodies is undeniably a target that tackles water scarcity and drought issues and comprises a non-stop quest for improved services and measures that satisfy this condition. The main challenge is, therefore, to cover the financial cost of construction and maintenance of big interventions. Another major challenge is to plan for reducing water scarcity under the increasing pressures of climate change projections. In the examined cases, water scarcity is expected to increase by the end of the 21st century; there is projection for temperature increase in the Mediterranean basin of up to 2 °C associated with significant decreases in precipitation, posing massive stress on the water bodies and introducing new hydrogeomorphological alterations. Drought of the foreseen extent is linked with severe water supply issues, groundwater aquifer depletion, changes in the physicochemical conditions and deterioration of the ecological status of water bodies, impacts in biodiversity, erosion and severe economic impacts primarily associated with the agricultural production. The projections on temperature increase are linked with intensification of extreme storm events, which when combined with the expected soil erosion, desertification and deforestation are expected to increase the intensity and frequency of flooding. The proposed measures would, therefore, have to address the new challenges, thus introduce structural measures, such as additional geomorphological alterations, climate resistant infrastructure

that are studied for extended return periods under the new conditions of water scarcity. Under current climatic pressures, water scarcity and drought have become increasingly frequent and widespread in the European Union. By 2007, more than 11% of Europe's population and 17% of its territory had been affected by water scarcity, fact that increases dramatically the cost of combating the impacts of drought with EU [48]. Along this line, and as an effort to focus on water scarcity issues, the EC issued the Communication document on "*Addressing the challenge of water scarcity and droughts*" adopted in 2007 [13], followed by the "*Policy Review for water scarcity and droughts*" in 2012 [14], which forms part of the "*Blue Print for Safeguarding European Waters*" also adopted in 2012 [15]. The aforementioned policy documents provided the framework of tools, to adequately fulfill the requirements of the PoMs and of the River Basin Management Plans with regard to water scarcity and drought. The measures outlined in the PoMs are consequential, thoughtful and comprehensive, still they are not yet fully implemented with their implementation being subject to covering the relevant costs. Criticism would consequently, lie on how could the river basin authorities ensure coverage of costs (capital, operation and maintenance) for the measures aimed to combat water scarcity particularly under the projected changes in climate. Furthermore, the development of a drought-resilient society requires long term strategies and commitment [49]. Integration, preparedness and mitigation as well as understanding of risks are keys to the successful implementation of plans [16].

Critique to the WFD implementation would be based on the fact that although it promotes extensive public and stakeholder involvement in the decision making process towards selecting the most appropriate and applicable measures, and it allows for continuously informed choices throughout the 3 implementation cycles, it does not guarantee how the new requirements, can be subject to adequate funding, especially under urgent or crisis conditions. Funding sources to support new interventions targeting to reduce vulnerability, to provide technical assistance and to support stakeholder awareness raising, yet have to be identified and ensured through the national legislation and regulatory schemes.

5. Conclusions

The WFD although does not directly and clearly address water scarcity issues, is supported by the associated regulatory documents and eventually set a complete/holistic framework for combating water scarcity and drought. In addition, the requirement to ensure good ecological status places a timeless and on-going target that can only be achieved if action is taken to combat major water stress issues and to ensure adequate water flow and availability to cover the demand. The WFD, as a groundbreaking piece of legislation, through the instruments it has introduced, namely the PoMs as part of the RBMPs, provides the framework to achieve good status of water resources. The 3 cycles of implementation provide opportunities for improvement. The PoMs in the examined case studies provide technical and hydrogeomorphological measures, as well as regulatory and legal instruments to enable the timely implementation of interventions and improve awareness levels on water management. Water scarcity conditions on the other hand are expected to intensify in the near future. Future climate change scenarios impose an increasing stress on the water resource management sector as indicated in the examined case studies. Predictions for the examined cases see decrease on precipitation of about 10–20% in the catchment areas with parallel changes on the intensity of rainfall events, increase on the average temperature also associated with increased rates of evapotranspiration. Uncertainties impose additional stress and are linked to unforeseen climate alterations, i.e. temperature increase above the threshold of 1.5 °C by 2050 [50], change in precipitation and evapotranspiration patterns, increased flooding and drought incidences, changes in the size of the estimated carbon budget, changes in the political and socioeconomic conditions in the regions also associated with budget allocation.

Implementation constraints for the PoMs are significant and are subject to the time required for the completion of all implementation cycles and to financial constraints. Budget constraints and funding issues would also have to be addressed especially regarding future water scarcity towards reaching the WFD environmental objectives. The timely implementation of water scarcity related measures requires for funding to support adaptation of measures especially under economic recession conditions,

as currently experienced in Greece. New sources of funding and technical assistance could be sought in order to reduce vulnerability and support successful and timely implementation. The implementation of the ‘user pays’ principle as a means for effective water pricing policies comprises as a main challenge towards full implementation of the WFD. This principle has the potential to enhance water savings and move towards a related culture. Furthermore, policy action on water scarcity and drought has to fill-in knowledge gaps and ensure data comparability across EU. Thus, emphasis should be paid on the strengthening of the monitoring programs, research and high quality national assessments.

Measures that receive public acceptance and promote changes in attitudes, such as adoption of water saving techniques and initiatives (i.e., changes in technologies used by individuals, replacement of old meters, economic measures to reduce consumption) should also be prioritized. Such measures, despite having a significant contribution into relieving stress from water resources, do not succeed unless stakeholders and the public are convinced and actively involved in all stages of implementation. Along this line, monitoring and implementation results should be adequately communicated to stakeholders whom would have to actively participate in co-formulating responses throughout the 3 cycles of implementation. Moreover, a comprehensive critique to the efficiency of the WFD in addressing water scarcity could be formulated at the completion of all implementation cycles; the implementation outcomes will inform next implementation steps and regulatory requirements.

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References

1. United Nations Development Programme. *Human Development Report 2006: Beyond scarcity: Power, Poverty and the Global Water Crisis*; United Nations Development Programme: New York, NY, USA, 2006.
2. Vorosmarty, C.J.; Green, P.; Salisbury, J.; Lammers, R.B. Global water resources: Vulnerability from climate change and population growth. *Science* **2000**, *289*, 284–288. [[CrossRef](#)] [[PubMed](#)]
3. Alcamo, J.; Doll, P.; Henrichs, T.; Kaspar, F.; Lehner, B.; Rosch, T.; Siebert, S. Global estimates of water withdrawals and availability under current and future ‘business-as-usual’ conditions. *Hydrolog. Sci. J.* **2003**, *48*, 339–348. [[CrossRef](#)]
4. Oki, T.; Kanae, S. Global hydrological cycles and world water resources. *Science* **2006**, *313*, 1068–1072. [[CrossRef](#)] [[PubMed](#)]
5. Falkenmark, M.; Berntell, A.; Jagerskog, A.; Lundqvist, J.; Matz, M.; Tropp, H. *On the Verge of a New Water Scarcity: A Call for Good Governance and Human Ingenuity SIWI Policy Brief, 2007*; International Water Institute (SIWI): Stockholm, Sweden, 2007.
6. Xia, J.; Duan, Q.Y.; Luo, Y.; Xie, Z.H.; Liu, Z.Y.; Mo, X.G. *Science Direct. Adv. Clim. Change Res.* **2017**, *8*, 63e67.
7. Koundouri, P. (Ed.) *Coping with Water Deficiency: From Research to Policy Making*; Springer Publishing: New York, NY, USA, 2008.
8. Koundouri, P.; Karousakis, K.; Assimacopoulos, D.; Jeffrey, P.; Lange, M. (Eds.) *Water Management in Arid and Semi-Arid Regions: Interdisciplinary Perspectives*; Edward Elgar Publishing: Cheltenham, UK, 2006.
9. Kumm, M.; Philip, J.; Ward, P.J.; de Moel, H.; Varis, O. Is physical water scarcity a new phenomenon? Global assessment of water shortage over the last two millennia. *Environ. Res. Lett.* **2010**, *5*, 034006. [[CrossRef](#)]
10. Karousakis, K.; Koundouri, P. *Water Management in Arid and Semi-Arid Regions: Interdisciplinary Perspectives, MPRA Paper 38231*; University Library of Munich: Munich, Germany, 2006.

11. EC, 2000. *Directive 2000/60/EC; The Water Framework Directive (WFD)*: Brussels Belgium, 2000.
12. EC, 2007a. *Communication from The Commission to The European Parliament and The Council Addressing the Challenge of Water Scarcity and Droughts in the European Union (COM/2007/414)*; The Water Framework Directive (WFD): Brussels, Belgium, 2007.
13. EC, 2012a. *Communication from The Commission to The European Parliament, The Council, The European Economic and Social Committee and The Committee of the Regions Report on the Review of the European Water Scarcity and Droughts Policy*; The Water Framework Directive (WFD): Brussels, Belgium, 2012.
14. EC, 2012b. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions-A Blueprint to Safeguard Europe's Water Resources*; The Water Framework Directive (WFD): Brussels, Belgium, 2002.
15. Kampragou, E.; Apostolaki, S.; Manoli, E.; Froebrich, J.; Assimacopoulos, D. Towards the harmonization of water-related policies for managing drought risks across the EU. *Environ. Sci. Policy* **2011**, *14*, 815–824. [[CrossRef](#)]
16. Kundzewicz, Z.W.; Krysanova, V.; Benestad, R.E.; Hov, O.; Piniewski, M.; Otto, I.M. Uncertainty in climate change impacts on water resources. *Environ. Sci. Policy* **2018**, *79*, 1–8. [[CrossRef](#)]
17. World Climate Research Programme. Available online: <https://www.wcrp-climate.org/> (accessed on 2 February 2019).
18. Koundouri, P.; Davila, O. *The Use of Ecosystem Services Approach in Guiding Water Valuation and Management: Inland and Coastal Waters*; Athens University of Economics and Business: Athens, Greece, 2013.
19. IPCC, 2014. Scenario process for AR5. Parallel phase: New narratives and scenarios. Available online: http://sedac.ipcc-data.org/ddc/ar5_scenario_process/parallel_nat_scen.html (accessed on 18 December 2018).
20. Ebi, K.; Hallegatte, S.; Kram, T.; Arnell, N.; Carter, T.; Edmonds, J.; Kriegler, E.; Mathur, R.; O'Neill, B.; Riahi, K.; et al. A new scenario framework for climate change research: Background, process, and future directions. *Clim. Change* **2013**, 363–372. [[CrossRef](#)]
21. O'Neill, B.C.; Kriegler, E.; Riahi, K.; Ebi, K.; Hallegatte, S.; Carter, T.; Mathur, R.; Vuuren, D. A new scenario framework for climate change research: The concept of shared socioeconomic pathways. *Clim. Change* **2013**, 387–400. [[CrossRef](#)]
22. Rozenberg, J.; Guivarch, C.; Lempert, R.; Hallegatte, S. Building SSPs for climate policy analysis: A scenario elicitation methodology to map the space of possible future challenges to mitigation and adaptation. *Clim. Change* **2013**, 509–522. [[CrossRef](#)]
23. Ker Rault, P.A.; Koundouri, P.; Akinsete, E.; Ludwig, R.; Huber-Garcia, V.; Tsani, S.; Acuna, V.; Kalogianni, E.; Luttk, J.; Kok, K.; et al. Down scaling of climate change scenarii to river basin level: A transdisciplinary methodology applied to Evrotas river basin, Greece. *Sci. Total Environ.* **2019**, *660*, 1623–1632. [[CrossRef](#)] [[PubMed](#)]
24. Kalogianni, E.; Vourka, A.; Karaouzas, I.; Vardakas, L.; Laschou, S.; Skoulikidis, N.T. Combined effects of water stress and pollution on macroinvertebrate and fish assemblages in a Mediterranean intermittent river. *Sci. Total Environ.* **2017**, *603*, 639–650. [[CrossRef](#)]
25. Mihas, S.; Efstratiadis, A.; Nikolaou, K.; Mamassis, N. Drought and water scarcity management plan for the Peloponnese river basin districts. In Proceedings of the 12th International Conference “Protection & Restoration of the Environment”, Skiathos Island, Greece, 29 June–4 July 2014.
26. Marinou, P.G.; Feloni, E.G.; Tzoraki, O.; Baltas, E. An implementation of a water balance model in the Evrotas basin. *Eur. Water* **2017**, *57*, 147–154.
27. Skoulikidis, N.T.; Sabater, S.; Datry, T.; Morais, M.M.; Buffagni, A.; Dörflinger, G.; Tockner, K. Non perennial Mediterranean rivers in Europe: Status, pressures, and challenges for research and management. *Sci. Total Environ.* **2017**, *577*, 1–18. [[CrossRef](#)] [[PubMed](#)]
28. Skoulikidis, N.; Vardakas, L.; Karaouzas, I.; Economou, A.N.; Dimitriou, E.; Zogaris, S. Assessing water stress in Mediterranean lotic systems: Insights from an artificially intermittent river in Greece. *Aquat. Sci.* **2011**, *73*, 581–597. [[CrossRef](#)]
29. Karaouzas, I.; Theodoropoulos, C.; Vardakas, L.; Kalogianni, E.; Skoulikidis, N. A review of the effects of pollution and water scarcity on the stream biota of an intermittent Mediterranean basin. *River Res. Appl.* **2018**, *34*. [[CrossRef](#)]

30. Hellenic Special Secretariat for Water; River Basin Management Plan (RBMP). *Management Plan for the River Basins of Eastern Peloponnese River Basin District*; Special Secretariat for Water-report; Hellenic Special Secretariat for Water: Athens, Greece, 2013.
31. Vernooij, M.G.M.; Querner, E.P.; Jacobs, C.; Froebrich, J. *Characterizing Temporary Streams*; Wageningen Alterra: Wageningen, The Netherlands, 2011; Alterra-report 2126.
32. Riahi, K.; Rao, S.; Krey, V.; Cho, C.; Chirkov, V.; Fischer, G.; Kindermann, G.; Nakicenovic, N.; Rafaj, P. RCP 8.5—A scenario of comparatively high greenhouse gas emissions. *J. Clim. Change* **2011**, *109*, 33. [[CrossRef](#)]
33. Thomson, A.M.; Calvin, K.V.; Smith, S.J.; Kyle, G.P.; Volke, A.; Patel, P.; Delgado-Arias, S.; Bond-Lamberty, B.; Wise, M.A.; Clarke, L.E.; et al. RCP4.5: A pathway for stabilization of radiative forcing by 2100. *J. Clim. Change* **2011**, *109*, 77. [[CrossRef](#)]
34. Cazemier, M.M.; Querner, E.P.; van Lanen, H.A.J.; Gallart, F.; Prat, N.; Tzoraki, O.; Froebrich, J. *Hydrological Analysis of the Evrotas Basin, Greece-Low Flow Characterization and Scenario Analysis*; Alterra Report: Wageningen, The Netherlands, 2011; ISSN 1566-7197.
35. Abahous, H.; Sifeddine, A.; Bouchaou, L.; Ronchail, J.; El Morjani, Z.E.A.; Ait Brahim, Y.; Kenny, L. Inter-annual variability of precipitation in the Souss Massa region and linkage of the North Atlantic Oscillation. *J. Mater. Environ. Sci.* **2018**, *9*, 2023–2031.
36. Agence du Bassin Hydraulique de Souss Massa - ABHSMMD. Ressources en eau de surface. In *Etude de Révision du Plan Directeur d'Aménagement Intégré des Ressources en Eau (PDAIRE) des Bassins du Souss Massa*; Université de Grenoble: Grenoble, France, 2007; Volume 2. (In French)
37. Knippertz, P.; Christoph, M.; Speth, P. *Meteorology of Atmospheric Physics*; Springer: New York, NY, USA, 2003; Volume 83, pp. 67–88.
38. Gleick, P.H. *Confronting Climatic Change: Risks, Implications, and Responses*; Cambridge University Press: Cambridge, UK, 1992.
39. Voskresenskaya, E.; Bardin, M.; Kovalenko, O. Climate Variability of Winter Anticyclones in the Mediterranean-Black Sea Region. *Quat. Int.* **2016**, *409*, 70–74. [[CrossRef](#)]
40. Hurrell, J.W.; Deser, C.; Phillips, A.S. North Atlantic Oscillation (NAO), Reference Module in Earth Systems and Environmental Sciences. *Encycl. Ocean Sci.* **2018**, 65–72. [[CrossRef](#)]
41. Bouchaou, L.; Choukr-Allah, R.; Hirich, A.; Ennasr, M.S.; Malki, M.; Abahous, H.; Bouaakaz, B.; Nghira, A. Climate change and water valuation in Souss-Massa region: Management and adaptive measures. *Eur. Water* **2017**, *60*, 203–209.
42. Diao, X.; Dinar, A.; Roe, T.; Tsur, Y. A general equilibrium analysis of conjunctive ground and surface water use with an application to Morocco. *Agric. Econ.* **2008**, *38*, 117–135. [[CrossRef](#)]
43. Elame, F.; Diukkali, R. Water Valuation in Agriculture under climate change (Case of Souss-Massa Basin, Morocco). In *Proceedings of the 2011 Conference: Impacts of Climate Change on Agriculture*, Rabat, Morocco, 6–7 December 2011.
44. Bouchaou, L.; Tagma, T.; Boutaleb, S.; Hssaisoune, M.; El Morjani, Z.E.A. Climate change and its impacts on groundwater resources in Morocco: The case of the Souss-Massa basin. In *Climate Change Effects on Groundwater Resources: A Global Synthesis of Findings and Recommendations*; IAHR/Taylor & Francis: Goring Reading, UK, 2011.
45. El Badraoui, M.H.; Berdai, M. *Adaptation of the Water-Energy System to Climate Change: National Study-Morocco*; Plan Bleu: Marseille, France, 2011.
46. Seif-Ennasr, M.; Zaaboul, R.; Hirich, A.; Nils, G.; Bouchaou, L.; El, Z.; El, A.; Hassane, E.; McDonnell, R.A.; Choukr-Allah, R. Climate change and adaptive water management measures in Chtouka Ait Baha region (Morocco). *Sci. Total Environ.* **2016**, *573*, 862–875. [[CrossRef](#)] [[PubMed](#)]
47. Barceló, D.; Sabater, S. Water quality and assessment under scarcity: Prospects and challenges in Mediterranean watersheds. *J. Hydrol.* **2010**, *383*, 1–4. [[CrossRef](#)]
48. European Environment Agency (EEA). *Europe's Environment: The Fourth Assessment*; European Environment Agency: Copenhagen, Denmark, 2007.

49. United Nations International Strategy for Disaster Reduction. *Drought Risk Reduction Framework and Practices: Contributing to the Implementation of the Hyogo Framework for Action*; United Nations Secretariat of the International Strategy for Disaster Reduction: Geneva, Switzerland, 2007; p. 98.
50. Intergovernmental Panel for Climate Change (IPCC); Masson-Delmotte, V.P.; Zhai, H.-O.; Portner, D.; Roberts, J.; Skea, P.R.; Shukla, A.; Pirani, W.; Moufouma-Okia, C.; Pean, R.; et al. *Sixth Assessment Report (AR6)—Global Warming of 1.5 °C: An IPCC Special Report on the Impacts of Global Warming of 1.5 °C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, In the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*; IPCC: Geneva, Switzerland, 2018.



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