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Participatory Evaluation of Water Management Options for Climate Change Adaptation in River Basins

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Citation: Sanchez-Plaza, A.; Broekman, A.; Retana, J.; Bruggeman, A.; Giannakis, E.; Jebari, S.; Krivograd-Klemenčič, A.; Libbrecht, S.; Magjar, M.; Robert, N.; et al. Participatory Evaluation of Water Management Options for Climate Change Adaptation in River Basins. *Environments* **2021**, *8*, 93. https://doi.org/10.3390/environments8090093

Academic Editor: Yu-Pin Lin

Received: 31 July 2021
Accepted: 8 September 2021
Published: 10 September 2021

Abstract: Climate and other human-induced changes will increase water scarcity in world areas such as in the Mediterranean. Adaptation principles need to be urgently incorporated into water management and stakeholder engagement needs to be strengthened at all steps of the management cycle. This study aimed to analyse and compare stakeholder-preferred water management options (WMOs) to face climate change related challenges and to foster adaptation in four Mediterranean river basins. The challenges and WMOs of the four river basins identified by stakeholders were analysed examining to what extent the WMOs tackled the identified challenges. The impact of the WMOs resulting from a participatory modelling method was included in a comparative analysis of the stakeholders' WMOs preferences. The results indicate the participatory approach that was applied allowed local priorities and real-world challenges to be defined with adequate detail as well as the definition of tailored responses. The participatory impact analysis provided an integrated view of the river basin as an interrelated system. The participatory evaluation of the WMOs was able to consider a wide range of elements and was able reflect the combined preferences of the stakeholders. Moreover, it allowed groups of basin actors with highly diverse profiles and concerns to further promote sets of these WMOs as input into decision making processes.

Keywords: adaptation; climate change; stakeholder engagement; participatory evaluation; river basin; water management

1. Introduction

Adequate water availability is of the utmost importance for the sustainability of social and ecological systems [1]. Depending on the region, the impacts of climate change on water resources will have adverse consequences on the availability of water resources to a different extent. The Mediterranean region is expected to be intensively affected by drier conditions [2], an increase in annual average temperature (hence higher evapotranspiration), a decrease in annual rainfall with changes in its seasonal distribution, higher inter-annual rainfall variability, and an increase in the occurrence of extreme events (droughts and floods) [3]. This complex picture is exacerbated if we consider other human-induced changes affecting water resources [4], such as land cover and land use changes, urban sprawl, and changes in population. These conditions are expected to negatively affect water quantity and quality and result in different impacts (e.g., increased concentration of pollutants, increased salinity, groundwater depletion, loss of connectivity), putting e the already precarious water balance in the region more at risk and threatening water availability for multiple uses, including for the environment.

In this context of increased water scarcity and increased rainfall extremes, there is a pressing need to incorporate adaptation principles into water management at all policy and governing levels to guarantee sustainability. Different policies tackling natural resource management at both the European and national levels offer a useful framework to develop concrete adaptation strategies, aiming to meet the threats and challenges imposed by climate and other anthropic-related changes. Thus, regarding water, a set of norms and principles are included in the Water Framework Directive (WFD) [5] and the Floods Directive [6] and are mainstreamed through the implementation of river basin management plans (RBMPs) in subsequent management cycles, including in specific action plans tackling extreme climatic events such as floods and droughts [7]. This policy framework offers an adequate instrument to makes advances in the consideration of climate change-related adaptations in water management [8]; however, success has been limited in previous management cycles [9], and further advances are needed to incorporate the likely impact of climate change and to consider national climate change strategies and to develop coordinated adaptation measures [10]. Furthermore, the main objective of WFD is to protect and enhance aquatic ecosystems, and it is grounded in the promotion of the sustainable use of water in the European member states [11]. This European legislation puts the absolute necessity of achieving sustainability to meet present and future water use needs at the center of water management, as it related to the UN Sustainable Development Goals (SDGs), many of which have targets directly or indirectly related to water [12].

Given the need to tackle tradeoffs and to build compromises between different sectoral vested interests on natural resource use and to preserve common sources, the WFD promotes a holistic approach to protect river basins, including a strong call for engaging stakeholders to participate in the different stages of the planning cycle [13]. Participation feeds the policy design process with updated and relevant information on pressures and impacts, includes social and economic perspectives, and suggests solutions that might rely on wide acceptance from local actors [14]. The importance of stakeholder engagement when considering adaptation to climate change more globally claims similar collective contributions to face the huge and urgent challenges ahead [15,16]. This engagement increases the quality of decision-making processes [17,18] by combining the different skills, theoretical backgrounds, and experiences required to deliver better answers in a context characterized by a high degree of uncertainty regarding the issues at stake [19].

Participation calls for the ability to integrate different types of information: science-based knowledge, experience-based knowledge, socio-economic context information, amongst others. Different methods and tools are available to promote the involvement of stakeholders in the analysis of climate change impacts, in the co-design solutions as well as in the monitoring and evaluation of the implementation process of these solutions. Over the last few years, different participatory modelling methodologies [20,21], such as fuzzy cognitive mapping or agent-based modelling, have been applied in natural resource management to incorporate knowledge of different natural environments together and thus achieve a more complete understanding of the functioning and interdependencies of complex systems [22,23].

In this study, we show how a participatory approach can be implemented in real cases. In particular, we highlight how this technique can be used to prepare river basin management plans that take climate change as well as socioeconomic challenges into account. The novelty of the study lies in the practical experience and the lessons learnt from engaging stakeholders in different basins facing climate change issues, following a single approach in all cases. It shows the practicability of the methodology and its usefulness in different contexts, with a diverse composition of the stakeholders involved.

Complementing and building on the methodological description of the participatory approach developed in Verkerk et al. [24], the overall aim of our study was to further analyse and compare stakeholder-preferred water management options (WMOs) to face climate change-related challenges and to foster adaptation in four river basins in the Mediterranean: Pedieos in Cyprus, Tordera in Spain, Rmel in Tunisia, and Vipava in Slovenia. These basins represent a wide range of social and environmental characteristics in the Mediterranean region, with all of them having water resources that are vulnerable to climate change impacts; thus, the study could be relevant for any vulnerable river basin in the region and beyond. We have undertaken this study in order to answer various research questions: Are the challenges and WMOs similar or different between river basins? Do WMOs adequately respond to all of the challenges detected? Which WMOs are preferred by stakeholders in each river basin? To do this, the objectives of the study are to (i) define and compare the challenges and WMOs of the four river basins, (ii) analyse how the identified WMOs tackle the challenges of each river basin, (iii) analyse the impact of WMOs on the river basin through a participatory modelling method, and (iv) evaluate the stakeholder's preferences regarding WMOs through a multi-criteria analysis. Our research hypothesis is that a fully participatory approach, similar to the one that we present, allows for the adequate incorporation of water management adaptation strategies and that its application is valid in diverse contexts.

2. Materials and Methods

2.1. Case Study River Basins: Characteristics and Stakeholders

The participatory evaluation of the WMOs was conducted in four river basins across the Mediterranean: the Vipava river basin (Slovenia), the Tordera river basin (Spain), Rmel river basin (Tunisia), and the Pedieos river basin (Cyprus), which are located in the four cardinal points of the Mediterranean (Figure 1).

Figure 1. Location of the four case study river basins.

The four case study river basins (CSRB) are characterised by contrasting climates, natural ecosystems, land uses, and socio-economic aspects (Table 1), which represent part of the diversity in the Mediterranean.

Table 1. Characteristics of the four case study river basins.

CSRB (Country)	Pedieos (Cyprus)	Rmel (Tunisia)	Tordera (Spain)	Vipava (Slovenia)
Area (km^2)	120 km^2	870 km^2	865 km^2	589 km^2
Inhabitants	192,000	135,500	157,500	52,000
Mean annual temperature (°C) [1]	19.0	18.5	14.0	12.1
Mean annual precipitation (mm) [1]	320 to 670	350 to 600	650 to 1050	1500 to 2000
Main land uses	Forest (23%) Agriculture (65%) Urban (12%)	Forest (24%), Agriculture (75%), Urban (1%)	Forest (81%), Agriculture (10%) Urban (9%)	Forest (61%), Agriculture (33%) Urban (5%)
Key issues	High pressure on rivers by agriculture, industry, settlements, and river regulation.	High pressure on water resources by multiple users	Flooding, groundwater over-use, water quality	Limited resources and increasing tensions

[1] reference period: 1984 to 2008 for Tordera and 1981 to 2010 for Rmel, Pedieos, and Vipava. Range shown stands for elevation.

In each CSRB, dialogue and collaboration with local communities was promoted through an iterative process of mutual learning, participatory techniques, and a bottom-up approach integrated in a science-based methodology; a detailed description of this approach is described in Verkerk et al. [24]. The objective was to ensure that stakeholders could play an active role in determining appropriate strategies for the management of the river basins and could contribute to the key steps of the formulation and evaluation of the WMOs to meet climate change-related challenges [25–28]. Different types of interaction with stakeholders were performed during the co-design process, such as interviews, consultations, and workshops. Stakeholder involvement, from identification to selection and engagement, was structured following the Stakeholder Integrated Research (STIR) Approach [29].

The stakeholders were identified and selected following the Criteria, Quota, and Individuals method (CQI) of the STIR Approach, which aims to create a diverse and balanced group of participating stakeholders [29]. At first, each CSRB had to build its map of actors to be engaged in the process by interviewing key stakeholders and by conducting public meetings. The participants represented the main interest groups of the basin, including participants who were involved in activities such as agriculture, forestry, tourism, education, entrepreneurial endeavours, environmental and social associations as well as participants who were public authorities at the municipal and regional levels, researchers, experts, and lay people. Diverse criteria were applied together with the quota to guide the selection of participants (more details in Verkerk et al. [24]). In each basin, the composition of the groups of participants was different in accordance with the main local challenges and conditions. In Vipava, 93 people participated in the co-design process, and agriculture was the main sector represented, and we found high interest from the local administration, even though strong difficulties arose at engaging national level administrations. In Rmel, 130 people participated in the co-design process, and the process engaged a broad variety of actors who were interested and active. Notably, the education sector was strongly engaged, and due to the importance of the water sector in this region, engineers and researchers also actively participated. In Pedieos, 145 people participated in the co-design process, and the group of actors engaged was composed of community leaders, agricultural and environmental researchers, farmers, educators, consultants and officials working with the river basin, and people working in the agriculture and urban planning sectors. In Tordera, 88 people participated in the co-design process, and the group of participants covered different relevant sectors, but given that forests occupy 80% of land, the forestry sector was strongly represented.

2.2. Challenges and Water Management Options in Each Basin

A first series of workshops and interviews with local key stakeholders was held with the aim of presenting the project and to introduce the work. The stakeholders were asked to share interests and concerns regarding the river basin's current and desired state, its social and economic context, and how they the perceived risks and expected impacts of climate change. The results of the workshops were presented in the form of narratives for each river basin. These first conversations allowed the identification of the main challenges to be addressed in each basin, in other words, specific issues that require the development of concrete actions.

In all four river basins, 'water quality' and 'water quantity' were deliberatively included as challenges to ensure that the central elements of current river basin water planning in line with the WFD [5] as well as the basin's key vulnerabilities to climate change were tackled in an integrated manner. Furthermore, in each river basin, other challenges were formulated in accordance with specific issues that were at stake locally. For Vipava, 'water availability during droughts in growing season', and 'flood risk reduction' were highlighted as key challenges. In Rmel, the range of identified challenges also included 'agriculture', 'forestry and biodiversity management', and 'awareness of society' as well as 'human resources and employment'. In Pedieos, 'water quality' and 'water quantity' were tackled separately for groundwater and surface water, and the list of identified challenges also included 'flood risk'. In Tordera, special concerns were raised about the 'health of forests and water ecosystems' as well as the challenge of implementing 'integrated water management principles'.

Aiming to tackle the identified challenges, stakeholders contributed with potential WMOs during a specific workshop in each basin. WMOs are understood as concrete actions to be undertaken to change the pressures on the status of a water basin while taking global changes into account. According to our methodology, these WMOs had to address at least one of the specified challenges, and each challenge had to be tackled by several WMOs [24].

The WMOs that were developed were characterised using a set of 19 pre-defined descriptors (Table S1 in the Supplementary Materials) covering a wide range of elements that can be grouped into four typologies: (1) climate change adaptation potential, described by character, effectiveness, approach to adaptation, nature of the approach, potential to address climate change, feasibility, and acceptability; (2) costs and timing, described by implementation time horizon, expected lifetime, time lag between implementation and effectiveness, implementation costs, and operational costs; (3) features of the targeted basin, described by water status, water bodies, river section, extreme events, and implementation scale; (4) targeted uses, described by the water use sector and land use.

From the total 19 descriptors used, we selected four from the climate change adaptation potential typology to analyse relevant differences and to compare the characteristics of the WMOs defined in each river basin (see Table 2). The character of a WMO describes how to face water needs. The approach used to adapt a WMO describes the technical design of a solution and the means by which it reduces vulnerability to climate change and creates resilience. The feasibility of a WMO describes the degree of eventual obstacles to implementation. The acceptability of a WMO describes if there are any reasons a priori to reject an option.

The list of WMOs and their characteristics were contrasted and agreed upon among the stakeholders in specific participatory events for each of the four river basins. Once the WMOs were defined and characterised, it was possible to analyse to what extent these solutions could contribute to tackling the challenges and to decreasing the pressures on the water basin while taking climate change impacts into account.

Table 2. Classes of each of the selected descriptors for the comparison of water management option (WMOs) characteristics in the four river basins.

Descriptor	Classes	Explanation
Character	Demand	Option targeting the need for water
	Supply	Option targeting the availability of water
	Support	Option targeting improved governance (including awareness raising, monitoring, and stakeholder involvement)
Approach to adaptation [1]	Environmental conservation	Option targeting the recovery of the ecological status
	Green	Ecosystem-based approaches
	Grey	Technological and engineering solutions
	Soft	Managerial, legal, and policy approaches that change human behaviour and styles of governance
Feasibility	No major obstacles	The implementation could be initiated straightaway, e.g., missing information or technical details or no obstacles at all
	Minor obstacles	Some interventions are needed, but the implementation can be planned, e.g., costs and timing, responsibilities, political context
	Serious obstacles	The implementation will not happen until the obstacle is removed, e.g., legal barriers, serious cost or timing mismatches, and administrative hindrances
Acceptability	High	There are no significant reasons a priori for anyone to reject the option
	Low	There are significant reasons a priori for someone to reject the option

[1] From Adaptation in Europe [30].

2.3. Fuzzy Cognitive Maps

The stakeholder-based approach undertaken in this study incorporated the use of participatory modelling methodologies, specifically Fuzzy cognitive mapping [31–33], which is representations of a system as perceived by individuals. This methodology was chosen because it can be used to capture knowledge and to facilitate communication between stakeholders from various sectors and backgrounds as well as experts, ensuring that models of the studied system are being constructed in an understandable way [34–36]. Fuzzy Cognitive Maps (FCMs) have been widely used to depict the functioning of natural systems [37–42] and more specifically water resources use and management and climate change related impacts [43,44]. We used FCMs to represent the functioning of the river basins as they had been described by the stakeholders in an initial workshop and later written as narratives. The FCMs incorporated the basic elements of the functioning of the river basins as factors including, when possible, the challenges identified in each basin. Furthermore, climate change (changes in precipitation and temperature) was added into the map as an external driver affecting the system. The relationships between the factors were depicted as arrows with a determinate sign (positive or negative) and strength (strong, medium, and weak).

The maps included a selection of a maximum of 20 main biophysical, social, and economic factors relevant in the basin, which were able to describe the dynamics of the basins and the interlinkages between the factors in qualitative terms. The FCM representation was converted into simple mathematical models and was used to assess the impact of the WMOs on each of the four river basins. An in-depth description of the FCM elaboration and application used in our study is given in Verkerk et al. [24]. Linear models were used for Rmel, Tordera, and Vipava, while a non-linear approach was developed in Pedieos. The FCMs were used as semi-quantitative models to assess how WMOs would affect the dynamics of each river basin.

2.4. Impact of the Water Management Options on the River Basin

The next step undertaken was oriented at evaluating the impacts of the WMOs for all basins using the FCMs. The developed WMOs are solutions that act on the river basin system, increasing its adaptation capacity by modifying the interactions between water uses and the water body. There were several possible ways to determine the effect of the WMOs in the map dynamics, such as by (i) modifying the initial relationships between factors, (ii) defining new relationships, (iii) introducing new factors and relationships, or by (iv) combining the above-mentioned possibilities. After implementing each WMO in the map and running the model, a new equilibrium was reached. The impact analysis of each WMO on the river basins was conducted by calculating and comparing the difference between the baseline scenario and the alternative scenario resulting from the implementation of the WMO in the map. Most of the challenges defined for the case studies were included as factors in the FCMs; therefore, the impact of the different WMOs on the challenges that had been initially identified could be assessed. A detailed description of this methodology is described in Verkerk et al. [24].

2.5. Multi-Criteria Analysis

Multi-criteria analysis techniques, which are used to compare and rank alternatives through a set of evaluation criteria, are widely applied in water management [45]. After performing the impact analysis of the WMOs on the basin using the FCM and after taking into their characteristics into consideration, a stakeholder-driven Multi-Criteria Analysis (MCA) was conducted to make it possible to compare WMOs. In each river basin, we presented a list of evaluation criteria, the descriptors that characterized WMOs (Table S2 in the Supplementary Materials), and all of the factors from the FCMs except for drivers (Table S3 in Supplementary Materials) to the stakeholders in specific workshops. The workshop participants were asked to select the criteria that—according to their experience and opinions—needed to be used in the MCA of the WMOs. Then, for each of the selected criteria, the stakeholders indicated the values that represented the most and least preferred outcome for them.

Successively, the stakeholders were invited to develop an individual exercise as way to weigh each criterion based on their preferred importance on a scale 1 to 10. The MCA incorporated all of the stakeholders' answers. The results were calculated as the average of the FCM scores (obtained in the modelling) weighted by the preferences. These results were presented on a scale of 0 to 100, with 0 being the lowest preference possible and being 100 the highest. In order to easily compare the MCA results between the river basins, scores indicating stakeholder preferences for WMOs were structured into preference categories. WMOs scoring below 40 were considered as having low stakeholder preference, scores between 40 and 70 were considered as having medium preference, and scores over 70 were considered as having high preference. A chi-square test was then performed with the categorised data to make comparisons between the MCA results for each river basin and to differentiate the degree of stakeholder preference that the WMOs from the studied river basins had achieved.

During the stakeholder session when the MCA was conducted, a first preliminary averaged outcome of the MCA was presented, and the participants' feedback was incorporated. Moreover, as a result validation procedure, the stakeholders were asked to review the formulation of the WMOs to better include the perspectives of the participants.

3. Results

3.1. Definition and Comparison of Challenges in the Four River Basins

The stakeholders from each river basin identified a variety of challenges, ranging from three in Vipava to six in Rmel (see Table 3). All four river basins included challenges related to 'water quality and quantity' due to the importance of these factors in the state of the water bodies and their management needs. In Pedieos and Vipava, 'flood risk' reduction was considered a key challenge because of the frequency and intensity of flood damage on human activities occurring in those basins. In Rmel, the challenges covered broad aspects such as 'forest and biodiversity management', 'agriculture', and 'awareness of civil society' as well as 'human resources and employment' because the role of resource management was highly stressed in this basin. In the case of Tordera, stakeholders defined 'health of forests and water ecosystems' as well as 'integrated water management' as challenges given that they were very much aware of the importance of preserving ecosystem functionality and the connection between different water bodies.

Table 3. Climate change related challenges per river basin.

	Pedieos	Rmel	Tordera	Vipava
Water quality	√ [1]	√	√	√
Water quantity	√ [1]	√	√	√
Flood risk reduction	√			√
Health of forest and water ecosystems			√	
Forest and biodiversity management		√		
Agriculture		√		
Integrated water management			√	
Awareness of civil society		√		
Human resource and employment		√		

[1] For Pedieos, the water quality and water quantity challenges are differentiated between groundwater and surface water bodies.

3.2. Comparison of Water Management Options Characteristics

As a result of the interactions with stakeholders in all of the river basins, a final list of 102 specific WMOs were defined (Tables S4–S7 in the Supplementary Materials). The descriptors characterising these WMOs allow for their comparison within and among the case study river basins. The analysis of the four chosen descriptors (Table 4) shows the clear differences and diversity of the solutions proposed in the four river basins.

Table 4. Percentage of WMOs per river basin corresponding to each descriptor class for character, approach, feasibility, and acceptability. For some descriptors, more than one class could be chosen per water management option; thus, the total % may exceed 100% (these cases are marked with * in the Table).

WMO Descriptor	Classes	Pedieos	Rmel	Tordera	Vipava
Character	Demand	20	5 *	24 *	10
	Supply	7	32 *	6 *	30
	Support	36	32 *	24 *	30
	Environmental conservation	37	42 *	48 *	30
Approach to adaptation	Green	40 *	11	12	25
	Grey	33 *	63	15	35
	Soft	50 *	26	73	40
Feasibility	No obstacles	27	26	30	10
	Minor obstacles	63	48	55	80
	Major obstacles	10	26	15	10
Acceptability	High	67	42	82	85
	Low	33 [1]	58	18	15

[1] For Pedieos, the water quality and water quantity challenges are differentiated between groundwater and surface water bodies.

(a) Character: Pedieos and Tordera had the highest percentage of water demand-oriented WMOs, while Vipava and Rmel had the highest percentage of water supply-oriented ones. Pedieos had the highest support-oriented percentage, and Tordera the highest with environmental conservation character.
(b) Approach to adaptation: Pedieos had the highest percentage of WMOs adopting a green approach, while Rmel had the highest percentage of WMOs adopting a grey approach. Tordera was, by far, the basic with the most WMOs adopting a soft approach.

(c) Feasibility: Vipava had the lowest percentage of WMOs with no obstacles for their implementation. The least number of WMOs with major obstacles was found in Pedieos and Vipava, while Tordera and Rmel had a higher rate of major obstacles to overcome regarding WMO implementation.
(d) Acceptability: In all of the river basins except Rmel, most of the WMOs were considered to have high acceptability.

3.3. Analysis of How the Water Management Options Tackle the River Basin's Challenges

The WMOs were formulated to face the specific challenges that were detected (Tables S4–S7 in the Supplementary Materials). The way that this was done differed in each river basin:

1. For Pedieos (see Table S6 in the Supplementary Materials), 30 WMOs were identified. A total of ten of then tackled 'flood risk reduction', ten tackled 'quality and quantity of groundwater', and ten tackled 'quality and quantity of surface water' bodies. Although most of the WMOs tackled more than one challenge, each WMO was assigned to the challenge that it addressed the most.
2. In Rmel (see Table S7 in the Supplementary Materials), each of the 19 WMOs that were identified tackled one specific challenge. There were three WMOs that simultaneously tackled 'water quantity' and 'water quality'. There were four WMOs that addressed 'forest and biodiversity management', four that addressed 'agriculture', and three that addressed 'awareness of civil society'.
3. In Tordera (see Table S4 in the Supplementary Materials), most of the 33 WMOs that were identified tackled one specific challenge. There were five that addressed 'water quality', ten that addressed 'water quantity', eleven that addressed the 'health of forest and water ecosystems', and ten that addressed 'integrated water management'.
4. For Vipava (see Table S5 in the Supplementary Materials), from a total of 20 WMOs, six addressed all of the challenges, as they were related to raising awareness, governance, and environmental restoration as a strategy to reduce vulnerability. The other WMOs addressed at least two challenges. There were sixteen WMOs that addressed 'water quantity', ten that addressed 'flood risk reduction', and thirteen that addressed 'water quality'.

3.4. Analysis of the Impact of Water Management Options on the River Basin

We used Fuzzy Cognitive Maps (FCM) to analyse the impact of WMOs on the dynamics of the basins and on the challenges to be addressed (see the maps in Figures S1–S4 in the Supplementary Materials). The changes induced in each challenge by the implementation of each WMO for the Tordera river basin are shown in Figure 2, and those for the other three river basins are shown in Figures S5–S7 in the Supplementary Materials.

1. For the Pedieos river basin (Figure S7 in the Supplementary Materials), the smallest improvements were observed for the 'water quantity and quality of surface water' challenge for all WMOs compared to the baseline, and the highest were observed for 'flood risk reduction'. The 'water quantity and quality of groundwater' challenge had the highest number of WMOs contributing to a positive impact.
2. For the Rmel river basin (Figure S5 in the Supplementary Materials), the impact of the WMOs determined both positive and negative changes in the challenges compared to the baseline situation. The challenge achieving a larger improvement and less negative effects resulting from the WMOs implemented in the map was 'agriculture', followed by 'human resources and employment'. On the other hand, the challenges of 'water quality' and 'forest and biodiversity management' showed the highest negative impact from some of the WMOs considered.
3. In the Tordera river basin (Figure 2), the analysed WMOs had an overall positive impact, improving the state of the challenges compared to the baseline situation. The highest positive impacts were in the 'health of water ecosystems' challenge. It is interesting to note that the case for the 'water quality' challenge, where most of the

best performing WMOs were, were initially designed to tackle the 'health of forests and water ecosystems' challenge.

4. For the Vipava river basin (Figure S6 in the Supplementary Materials), the majority of WMOs had a very limited impact on the basin's challenges compared to the baseline. Few WMOs were able to provide improvement. Several WMOs induced worsening baseline conditions: reducing 'water quality' and 'water quantity' and producing decreases on 'flood risk reduction'.

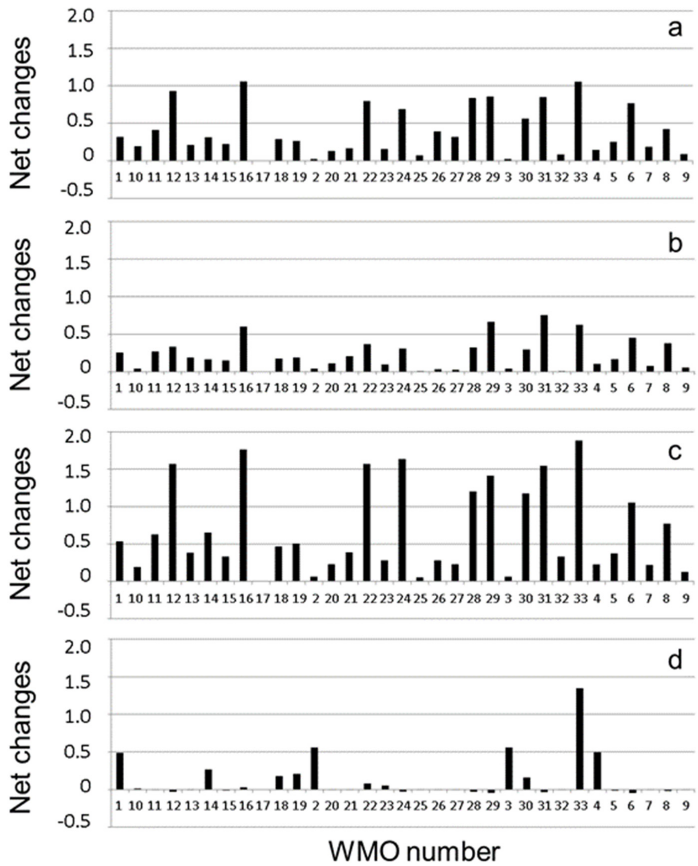

Figure 2. Impact assessment of WMOs on the Tordera river basin challenges included in the Fuzzy Cognitive Map (FCM) as factors: impacts on (**a**) 'water quality', (**b**) 'water quantity', (**c**) 'health of water ecosystems', and (**d**) 'health of forests'. The bars represent net changes from the baseline situation and show how each WMO (1 to 33) affects the river basin dynamics of the FCM model. Positive values correspond to the improvement of the challenge and negative values correspond to deterioration.

3.5. Evaluation of Stakeholder's Preferences Regarding Water Management Options

The resulting MCA scores indicating the stakeholder preferences for WMOs structured into preference categories ('low': below 40, 'medium': between 40 and 70, and 'high': above 70) are shown in Figure 3.

In order to compare the resulting MCA preferences obtained by the WMOs in the four river basins, a chi-square test was performed with the categorized data. The test showed clear differences among the four river basins ($\chi 2 = 57.8$ $p < 0.005$); thus, we can say that the set of WMOs developed per river basin was able to meet different degrees of stakeholder preferences. Pedieos had the most cases of low scoring WMOs; in Rmel, all of the WMOs had medium preference scores, while Tordera and Vipava had similar results, with WMOs scoring in all preference categories but with slightly more high preference values. Multi-Criteria Analysis results for each WMO in all four case study river basins are shown in Figure 4. Each WMO is associated with the challenge it tried to address.

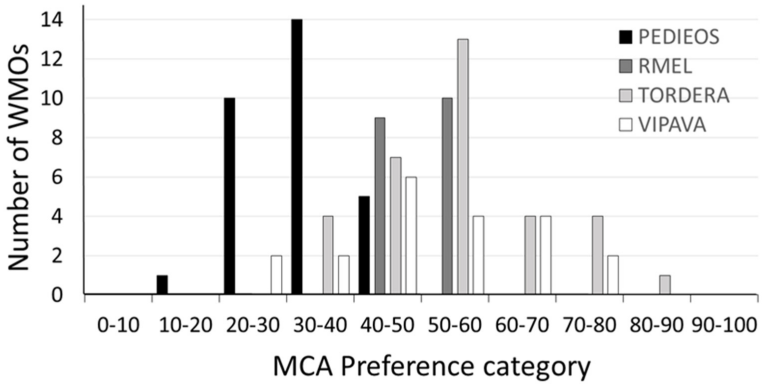

Figure 3. Number of WMOs per preference category taking the characterization and impact assessment criteria of the four river basins into account (classes of 10 units, from 0 to 100 of increased preference).

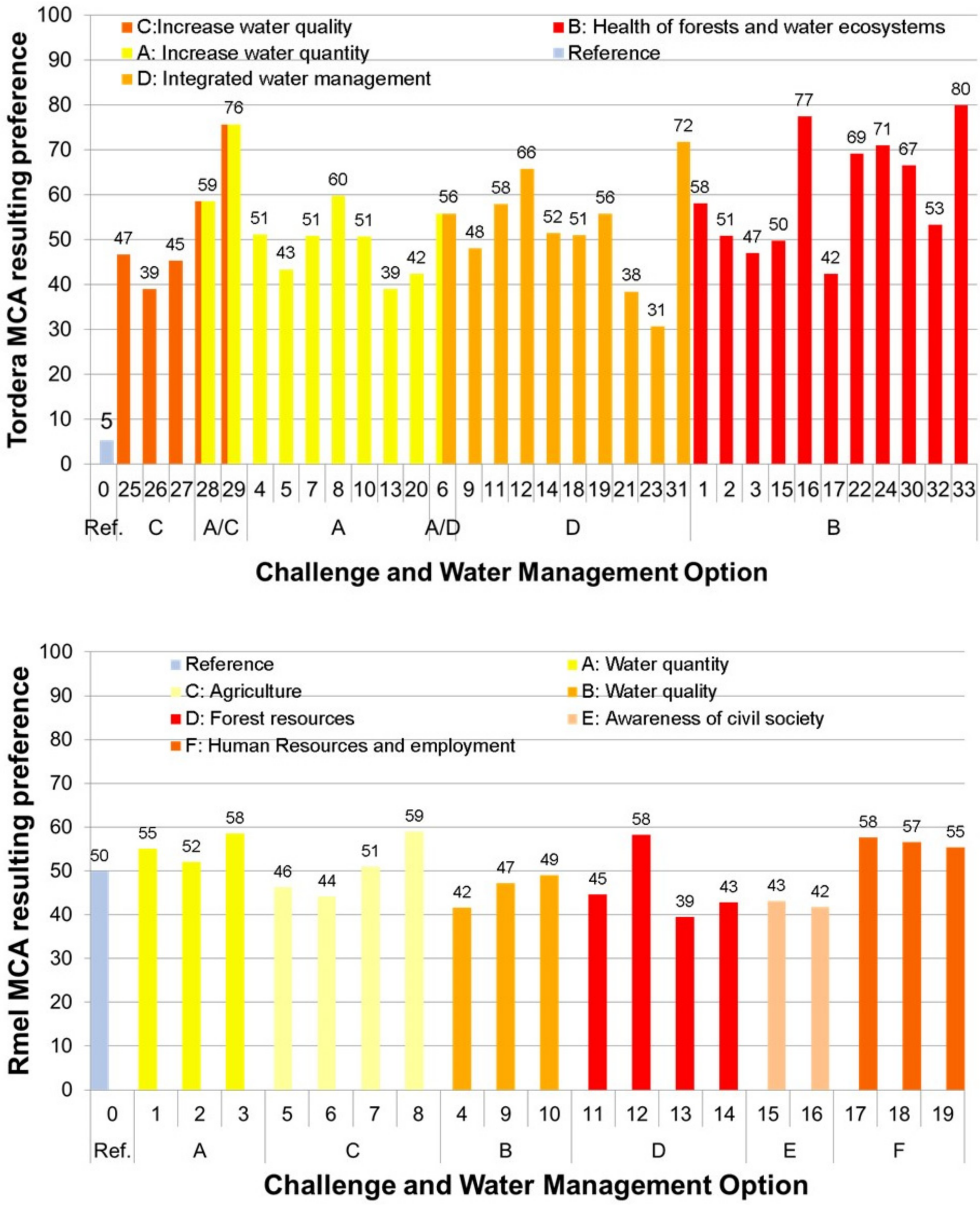

Figure 4. *Cont.*

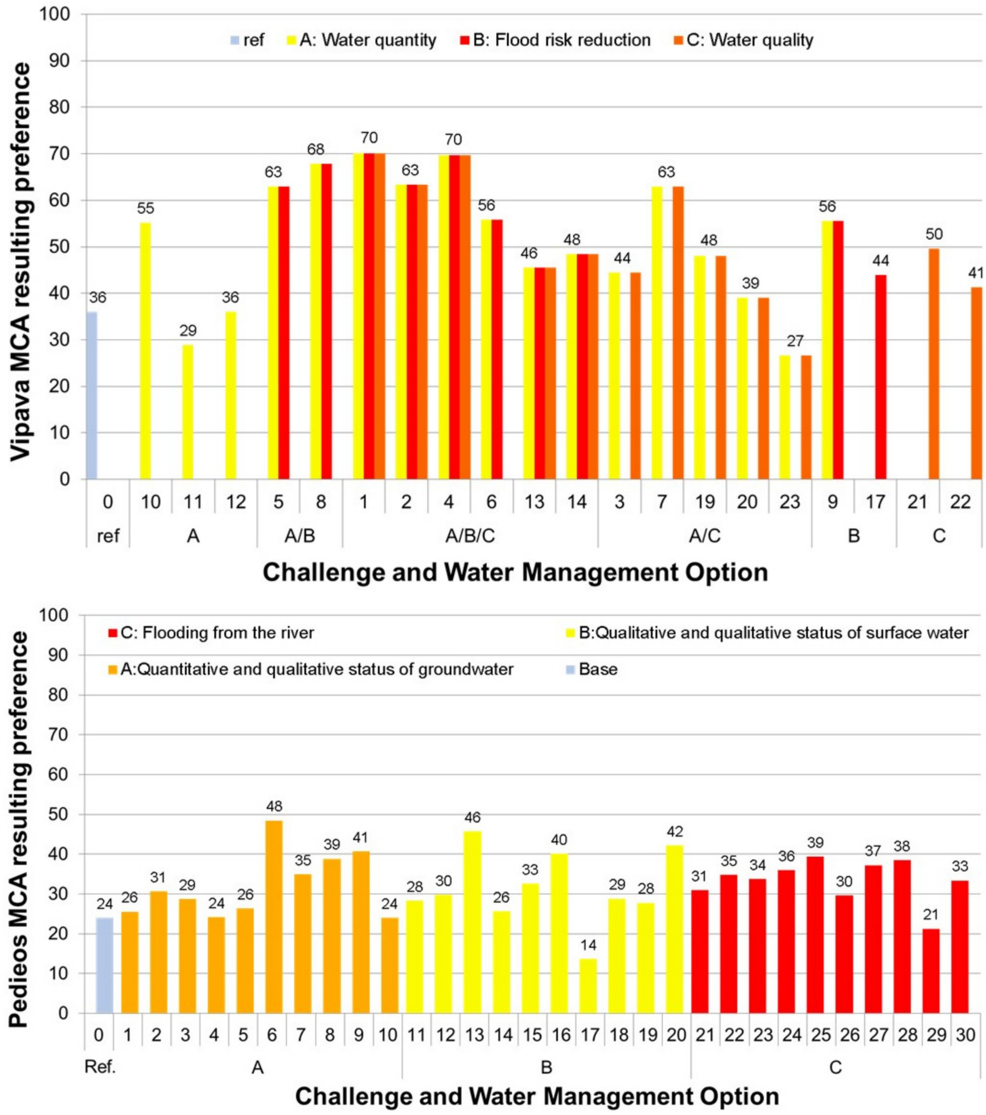

Figure 4. Multi-Criteria Analysis results based on the criteria derived from the impact assessment with the Fuzzy Cognitive Map and the characterization of the WMOs. Numbers on the x-axis refer to the WMOs for each river basin found in Tables S4–S7 in the Supplementary Materials. On the y-axis, preference values range from 0: least preferable to 100: most preferable. Bar colors represent the different challenges the WMOs were designed to tackle, which are also represented by letters in the x-axis.

In the case of the Tordera river basin, there were WMOs representing each preference score that addressed all changes, and there was at least one highly preferred WMO tacking each of the four challenges. For the Rmel river basin, all of the challenges were tackled by WMOs with medium preference scores. WMOs tackling the challenges 'water quality' and 'awareness of civil society' all scored below 50, while all the rest of the challenges were tackled by WMOs scoring slightly above 50. In Pedieos, two out of three challenges were tackled by at least one WMO with medium-ranked preference values. In Vipava, all of the challenges were tackled by at least one highly preferred WMO.

4. Discussion

Different studies identify common patterns regarding the challenges that need to be overcome in order to adapt to the impacts of climate change in the Mediterranean region [46]. Methodologies involving stakeholders, including representatives from the public authorities, allow these challenges to be pinned down specifically at the local level and invite water managers to consider the outcomes of science-based participatory practices that are able to deliver more in-depth assessments of stakeholder perceptions on management priorities. Such practices can mobilise transformative dynamics promoting sustainability across sectors to contribute to meeting SDG targets [47]. In this study, we aimed to analyse and compare the challenges and WMOs of four Mediterranean river basins. The challenges that were identified clearly reflect common stakeholder concerns regarding climate change impacts, human activities, and aspects related to natural ecosystems. The participatory approach that was applied was useful to define local features and key challenges with adequate detail, as expected from multi-institutional and multi-stakeholder frameworks [48]. Noticeable differences were identified between basins. Because of its concrete socio-economical context, Rmel is the only river basin where the stakeholders included some aspects directly linked to perceived societal vulnerability such as 'human resources and employment' and 'awareness of civil society' and economic sector performance such as 'agriculture' as challenges. In Tordera, the 'health of forest and water ecosystems' and 'integrated water management' challenges reveal strong concerns regarding environmental sustainability and the restoration of ecosystems. In this river basin, many stakeholders had intensively been involved in previous participatory processes, such as the ones linked to the WFD, and might have been especially aware of current environmental issues in the area. Pedieos and Vipava are the only river basins that specified 'flood risk' as a challenge because in these basins, flash floods are common.

Adaptation processes are complex [49] and so are the variety of responses that might be promoted to reduce the vulnerability to eventual impacts, triggering the broadening of the scope of conventional river basin assessments, thus motivating policy harmonisation and collaboration between different public authorities. The potential water management options that could contribute to meeting the challenges identified reveal the water management approach and principles of the stakeholders, at the same time revealing the strong interlinkages between territorial management and anthropogenic resource use and climate change-related vulnerability. This is quite clear when analyzing the portfolio of the WMOs that were identified in each of the river basins. For example, in Vipava and Rmel, the highest percentage of WMOs are water-supply oriented. Indeed, in these basins, the agricultural sector was very much involved and motivated to reduce the water supply risks that significantly affect the profitability of agricultural land use [50]. On the other hand, in Tordera, participant consensus on the management principles of the WFD aiming to achieve good ecological status induced the design of soft options with an environmental conservation character. During the participatory meetings, with the exception of those in Rmel, the participants strongly indicated the need for better normative frameworks, management decisions, and implementation to face the challenges ahead. This highlights the importance of political and social aspects in adaptation [51], especially considering decisions on land use and economic development that determine the status of water bodies (quantity and quality), often in a higher degree than climate change impacts alone. A high level of soft options shows that the participants see social and ecological tensions as opportunities for thinking and acting differently rather than as mere technical problems to be solved [52]. In Rmel, the stakeholders had a different perception, likely because they are not used to participating in management and because they are not familiar with European innovation in governance principles and practices. Nevertheless, stakeholders in all of the river basins acknowledged the important role of education, capacity building, and knowledge transfer, expressing that the participatory experience was positively contributing to improving water management, as shown in Verkerk et al. [24].

In terms of finding solutions to meet local challenges, all of the river basins produced WMOs tackling all of the challenges more or less specifically. Results show that some challenges were addressed by a higher number of WMOs than others. Given the fact that the challenges were broad and interrelated, the stakeholders found it difficult to define WMOs that would tackle each challenge on its own. Thus, in the Tordera, there were few WMOs exclusively targeting the 'water quality' challenge because the WMOs dealing with the 'health of forest and water ecosystems' were considered to have a big impact on the qualitative status of the water bodies due to the dynamics of the river basin.

Regarding the objective of analysing the impact of WMOs on the river basins through a participatory modelling method, indeed, the FCM impact analysis methodology allowed going beyond classical impact analysis and provided an integrated view of the river basins as systems. It made it possible to characterise the impact of WMOs on the whole system, including the indirect effects of changes oriented at one specific factor. Interestingly some of the WMOs designed specifically to address one challenge did not always have the most positive impact on that challenge. For example, in Tordera, some WMOs would positively impact the challenge of the 'health of water ecosystems' even though they were not initially designed to address this specific challenge. The reasons behind differences regarding the impact performance between case studies are determined by how the FCMs were structured, including the meaning behind the factors and how the relationship between the factors were established together with stakeholders as well as the choices made on how to interrelate the WMOs with the FCM. In Vipava, the modeling exercise shows that some WMOs are unlikely to achieve the desired impacts and, in some cases, may result in a worsening situation compared to the baseline conditions due to adverse interactions with other factors. When designing a WMO and the way it impacts the dynamics of the basin, assumptions are made about the effects on the different factors it addresses. These results underpin the idea that systemic analysis with FCMs allows the integration of the interaction between social, economic and environmental factors and can reveal potential weaknesses in the WMOs. However, one should remain cautious in the interpretation of the results. When designing a WMO and the way it impacts the dynamics of a basin, assumptions are made about the effects on the different factors it addresses. These assumptions are critical for the results of the FCM analysis.

Related to the aim of evaluating stakeholder preferences regarding WMOs through a multi-criteria analysis, the MCA methodology was used to find preferable solutions for adapting the river basins to global change but also to compare the performance of the WMOs. This methodology proves that it is able to consider a wide range of elements that are diverse in nature and that it is able to consider combined stakeholder preferences for different criteria, including elements from both the descriptors characterizing WMOs (purely qualitative) and the FCM-simulated impacts of the WMOs (semi-quantitative). The characteristics of the WMOS, for example, time spent between the implementation and the effectiveness of the WMO, the degree of its acceptability, or economic aspects, have high relevance in most results because they are highly preferred by stakeholders. Moreover, this high relevance is also due to the more direct effects of criteria linked to WMO characteristics, unlike the criteria linked to the impact assessment developed through the FCM that have a more nuanced and uncertain effects.

In Tordera and Vipava, the WMOs with high preference scores could be identified, while in Pedieos and Rmel, this was not the case. In fact, in Pedieos, most WMOs had low preference scores, while in Rmel, all of the WMOs had medium preference scores, not allowing differences to be shown between them effectively. Nevertheless, the results of the MCA can be used since they are meant to support complex choices where knowing the least attractive WMOs is as interesting as knowing the most attractive ones. Moreover, a water basin management plan usually includes several WMOs to tackle different aspects of the river basin's dynamics. If single WMO MCA scores are low in Pedieos—due to the fact that WMOs are highly challenge specific, i.e., WMOs have limited impacts on attributes not related to the challenge that they target—a collection of the best WMOs for each challenge would likely meet stakeholders' expectations. As the MCA results depict the combined preferences of a group of actors with highly diverse profiles and concerns, they can be used in the decision-making processes to develop management plans that will likely reach a high degree of acceptance. Moreover, in most cases, MCA results are in line with the presumed outcome of a WMO at the design stage, and in rare cases, they contrast. The details of the MCA scores can be then used to understand the source of the discrepancy between the MCA score and the presumed outcome and can explain the phenomenon to decision makers.

5. Conclusions

The participatory evaluation of WMOs for climate change adaptation in river basins provided results that could support public decisions. However, additional efforts are required to improve the participatory formulation of the WMOs. Moreover, a more detailed process of their characterisation could improve the responsiveness of the approach. Thus, diving more in depth and further modulating WMO characteristics could provide a refined analysis of stakeholder preferences. On the other hand, it is crucial to design the river basin dynamics so as to represent their specificities through the formulation of the FCM as close to actual reality as possible, as this will also determine if the impact of the WMOs is more or less adequate with respect to the initial aims and objectives that they were designed for.

It is important to remark that the efforts and approach adopted to identify and engage stakeholders in the process are crucial. The composition of the profiles included in the stakeholder databases need to be as broad as possible, and the approach to engage the actors identified needs to include the objectives to consolidate a balanced group of stakeholders who are available to assist throughout the different stages and moments of interaction required by the methodology. The importance of sound scientific and technical information being available to the participants is fundamental so as to ensure the quality and pertinence of contributions. The application of the combined methodology of co-designing the WMOs, FCM, and MCA in the four basins has been revealed to be an effective approach to obtain results at a low cost and over short time span. Moreover, it could allow groups of basin actors with highly diverse profiles and concerns to further promote sets of these WMOs as input into decision-making processes.

This study demonstrates that a fully participatory approach is able to adequately incorporate climate change adaptation in water management through the definition and evaluation of WMOs aimed at tackling climate change related challenges. It also proves that the application of the participatory approach is valid in diverse contexts and allows the consideration and comparison of basin features and stakeholder perceptions.

Further research opportunities would, for example, include broadening the focus and integrating water–energy–land nexus approaches with climate services in stakeholder led processes to improve policymaking and to provide elements to avoid maladaptation and at the same time search for synergies and co-benefits and to manage trade-offs among different sectors.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/environments8090093/s1, Table S1: Descriptors and their classes used to characterize WMOs, Table S2: WMO descriptors included in the MCA as selected criteria per river basin, Table S3: Factors from the WMOs impact assessment (FCM) included in the MCA as selected criteria per river basin, Tables S4–S7: Overview of the water management options per river basin, Figure S1–S4: Fuzzy Cognitive Map developed per river basin, Figure S5–S7: Graphs showing how river basin challenges are impacted by all WMOs.

Author Contributions: All authors contributed to the data gathering, initial analyses, and draft manuscript review for the study. A.S.-P. and A.B. (Annelies Broekman) compared and analysed the results across the four river basins with assistance from J.R.; A.S.-P. wrote the original draft with important contributions from A.B. (Adriana Bruggeman) and supervision from J.R. All authors have read and agreed to the published version of the manuscript.

Funding: This work has been funded through the European Union 7th Framework Programme, project BeWater (grant agreement 612385). The opinions expressed in this paper are those of the authors only.

Data Availability Statement: The data that support the findings of this study are available upon request from the corresponding author. The data are not publicly available because of privacy/ethical restrictions.

Acknowledgments: The authors thank all of the stakeholders for their active and constructive participation in the project, Elsa Varela, Inazio Martinez de Arano, Ines Saidi, Doha Zamel, Hédia Ezdin, Dalel Oussaifi, Hamed Daly-Hassen, Christos Zoumides, Katerina Charalambous, Marinos Eliades, Corrado Camera, Nataša Smolar-Žvanut, Sašo Šantl, Peter Suhadolnik, Špela Vrhovec, and all the rest of BeWater partners for their dedicated work within the project activities leading to this work.

Conflicts of Interest: The authors declare no conflict of interest.

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