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Review

How Can We Adapt Together? Bridging Water Management and City Planning Approaches to Climate Change

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Abstract: Different dynamics of climate change, population growth, and urbanisation challenge water service providers (WSPs) and those managing urban planning. The scientific community has been evidencing the concept of sustainable urban water management (SUWM) as a driver to foster the integration of the urban water cycle with its environmental, economic, and social sustainability dimensions. This article studies the approaches addressed by recent research on sustainable urban water management, focusing on the attention given by the scientific community to the way WSPs and city planners address the new challenges brought by climate change. A systematic review of existing literature shows how emergent challenges address the articulation between urban water cycle management and city planning. The results underline the need for the technical and economic evaluation of the overarching concept of SUWM systems, integrating values that go beyond financial issues; the need to address water scarcity not only from the supply side but also from the demand point of view; and the deepening of the relationship between new sources of water, such as the reuse, with the city planning in a context of climate change. Nevertheless, strategies for collaboration are still poorly addressed. The insights and gaps emerging from the analysis suggest new paths for research and practice in the field.

Keywords: climate change; adaptation; sustainable urban water management; city planning; urban planning; urban water management

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1. Introduction

The world is rapidly urbanising. From 1950 to 2020, the population residing in cities increased from 0.8 billion (29.6%) to 4.4 billion (56.2%), and recent projections point towards it could reach 6.7 billion (68.4%) by 2050 [1].

The latest IPCC report highlights that global net anthropogenic GHG emissions in 2019 were 12% higher than in 2010 and 54% higher than in 1990 [2]. The implied global emissions by 2030 exceed pathways consistent with 1.5 °C and are near the upper end of the modelled pathways range, which keeps temperatures likely to limit warming to 2 °C [2]. In urban environments, observed climate changes impact human health, livelihoods, and critical infrastructure systems, which will be increasingly vulnerable if their design does not consider changing climate conditions [3].

Controlling greenhouse gas emissions and conserving dwindling water resources while feeding and serving a growing population is, in fact, a daunting task [4].

Whilst in the last century, the population grew three times, water consumption increased six times, following the average level of income, the evolution of habits, and a different demand for food [5], increasingly dependent on water, which represents, on a global average, about 70% of water consumption [6]. The area needed for irrigated agriculture increased, and consequently, so did the water needed for its production, which in turn is a competitor of the water required for other uses, such as industry, hydroelectric power production [7], and urban.

Furthermore, managing water resources, essential for human life, economic activities, and ecosystem functioning faces enormous challenges in a changing climate. It is known that water availability is not evenly distributed in the territory or in time [8]. The effects of climate change, namely through extreme phenomena such as droughts or floods, make the management process even more complex. Extreme hydrological events such as prolonged droughts and floods are increasingly frequent, creating great uncertainty about cities' water security [9]. This context can compromise the objectives of the United Nations Sustainable Development Goals (SDGs), especially the SDG11 Sustainable Cities and Communities and the SDG6 Clean Water and Sanitation [10].

In the "excess of water" dimension, it can be seen [11] that urban areas are particularly vulnerable to strong rainfall episodes due to their impermeable surfaces (such as roads, parking lots, and roofs) that prevent rainwater infiltration and, consequently, increase surface runoff and the risk of rain flooding [12]. Urban sprawl and a potential lack of water storage capacity in rainfall peaks lead to an insufficient drainage capacity of the water system, resulting in rain floods [12,13].

In the "water scarcity" dimension, i.e., when demand exceeds availability, the health and wellbeing of citizens, the quality of the urban environment, and socio-economic development are put at risk [8]. Related to the phenomena of scarcity due to climate change, the adoption of water reuse or rainwater harvesting efforts is critical, especially when considering urban development needs in warmer climates, the decline of water resources, the difficulty of transporting water between basins, and efforts to increase sustainability in urban planning and management [14–17].

On the one hand, water service providers need help with new problems concerning adaptation to climate change and the simultaneously evolving context, such as population growth, increasing urbanisation, and changes in consumption patterns [18,19]. On the other hand, critical aspects of managing the supply/demand balance are related to the dynamics of the territory and how the spatial planning and demography introduce new needs and consumption patterns [20], as well as new threats. For example, spatial distribution and consumption habits in the Barcelona region led to water consumption about ten times higher in peripheral areas (typically houses with lawns) compared to the urban core area with multifamily buildings [21]. Another challenge has to do with how these drivers call land planning for new solutions that integrate not only the necessary resilience to extreme drought and flood phenomena but also contribute to positive externalities at the level, for example, of blue and green infrastructures, enabling a better urban environment and improving the quality of life of populations [22–25]. Adapting cities to the effects of climate change on the water cycle is, therefore, a pressing issue. This involves assessing the adequacy of existing (often obsolete) infrastructures and their resizing and adaptation, whether in terms of the asset or how it is operated. Given the complexity of these challenges and the issues that must be addressed, including how and when they should be tackled, it requires the involvement of different actors in urban planning and water governance as well as risk management [26–28].

Entities responsible for managing the urban water cycle and associated social and ecological needs (water services, regulators, legislators) are thus called upon to rethink their decision-making processes [29]. However, they cannot act alone. The challenges of climate change reinforce the importance of the interrelationship between the management of water management services and the entities responsible for the planning and management of the urban territory [20,30]. The relative location of the economic activities that consume/reject water and the socio-economic relationships are aspects to consider for sound management of water resources, considering the supply, demand, and sustainability of the entire urban water cycle.

Faced with emerging water management challenges in cities, Marlow et al. ([31], p. 2) propose the overarching concept of sustainable urban water management (SUWM) "as an aspiration, SUWM reflects a generalised goal to manage the urban water cycle to produce more benefits than traditional approaches have delivered". Hurlimann and Wilson ([30], p. 1) consider that even if the concept of SUWM is not definitively enshrined, it "implies the consideration of climate change and the inclusion of both supply and demand side initiatives".

From what has been said, given the context of rapid change that is approaching, reaching "sustainable urban water management" is necessary [30].

While several studies have covered different aspects of the relationship between climate change, spatial planning, and the water cycle over the last few years, to our knowledge, there has yet to be a study that identifies, catalogues, and integrates consolidated expertise in these fields. Thus, this article aims to clarify and systematise existing knowledge, to systematise learnings and gaps, and to point out approaches that need further development. It undertakes a literature review focusing on two major questions: (i) What are the main themes addressed by contemporary research on sustainable urban water management? (ii) How is the scientific community addressing the collaboration between water management and urban planning agencies, and how is the relationship between climate change and the urban water cycle considered?

In this context, research and related dissemination become increasingly essential to support decision makers, water service providers, and communities for more robust climate change adaptation, infrastructure design, and operation in a potential new urban landscape. The article is organised into five sections. Following this introduction, Section 2 describes the methodology used to undertake the literature review. Section 3 presents the results, and Section 4 discusses the findings, insights, and gaps. Section 5 presents the main conclusions.

2. Methodology

A systematic literature review was chosen to identify, analyse, and interpret all the available research in this domain. This section describes the methodological process to initiate the search and to collect, screen, and analyse selected papers from the existing literature.

This review was conducted based on the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines to guarantee the review process's reproducibility, traceability, and transparency. The review's objective is to find and analyse scientific literature framing urban adaptation in the context of climate change and its articulation with the urban water cycle and, with this, to respond to the research questions previously presented. Chronologically these steps were followed:

(a) The search string used in this review was first initiated by selecting an initial list of 15 relevant articles based on the expertise of the authors in the field, which were also chosen in the final set considered for analysis;

(b) Out of these articles, the first set of keywords was chosen and considered in the first search. Next, several test searches were performed with alternative combinations between keywords and their variants. The results from the test searches were discussed among the authors to refine the search strings until we were fully accomplished with the capability of the string to detect as much of the initial set of relevant and related publications as possible. The search strategy and results are presented in Table 1;

(c) Following this iterative strategy and after a series of test executions and reviews, which led to the selection of articles considered to be more relevant, we obtained the selected and unique set of search terms and keywords: climate change, sustainable urban water management, urban planning, and city planning. This step led to identifying 328 articles (from an initial universe of 524 items, from which we excluded the non-articles). The articles identified by the search engine were directly extracted into an Excel file offered by Scopus;

(d) For the quality evaluation, that is, relevance to the response to the research questions, the PRISMA tool was used for each article, providing an objective comparison between the articles and their classification, which resulted in a universe of 39 articles;

Table 1. Results of the combination of keywords in the iterative process.

Search Strategy for Scopus Conducted on 18 October 2022 Period: until 18 October 2022 Language: English Document Type Limits: Scientific Articles in Journals Search within the Title, Abstract, and Keywords		
Iteration	**Query**	**Records Retrieved**
a	(TITLE-ABS-KEY (climate AND change) AND TITLE-ABS-KEY (urban AND planning) AND TITLE-ABS-KEY (water AND reuse))	33
b	(TITLE-ABS-KEY (climate AND change) AND TITLE-ABS-KEY (water AND utilities) AND TITLE-ABS-KEY (municipalities))	25
c	(TITLE-ABS-KEY (climate AND change) AND TITLE-ABS-KEY (urban AND planning) AND TITLE-ABS-KEY (water AND management))	867
d	(TITLE-ABS-KEY (risk) AND TITLE-ABS-KEY (urban AND planning) AND TITLE-ABS-KEY (water AND management))	828
e	(TITLE-ABS-KEY (climate AND change) AND TITLE-ABS-KEY (sustainable AND urban AND water AND management))	667
f	(TITLE-ABS-KEY (climate AND change) AND TITLE-ABS-KEY (sustainable AND urban AND water AND management) AND TITLE-ABS-KEY (urban AND planning) OR TITLE-ABS-KEY (city AND planning))	328

The next step of filtering was performed to select additional relevant papers through the snowballing process. This step added 40 other articles and reports to the 15 previously identified.

Figure 1 synthesises the screening process and the number of articles excluded from the initial database and those that were added later. After concluding this screening process, the resultant set of articles was extracted into a final Excel file.

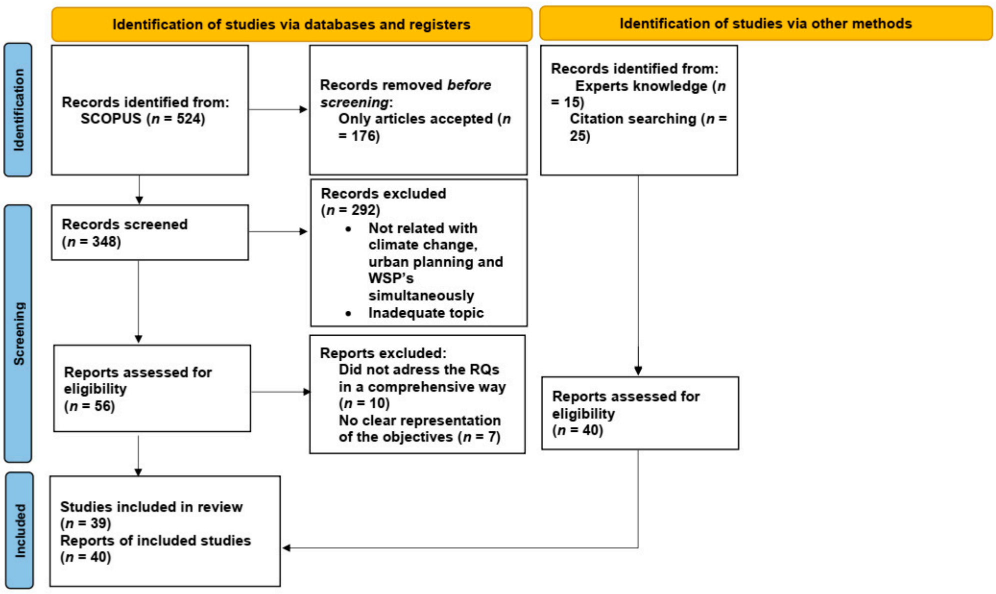

Figure 1. Methodological flow diagram summarising the steps to retrieve the articles (PRISMA).

3. Results and Content-Based Analysis

This section analyses the content of the selected articles, searching for how water service providers and urban planners respond to the challenges of climate change and how they respond, when they do, together. The information obtained is systematised and integrated into figures and tables. The presentation of results is first concentrated on the bibliometric analysis, then on the scientific literature, and finally on the grey literature.

3.1. Bibliometric Analysis

The evolution of articles published in recent years related to the selected keywords is represented in Figure 2, which shows a very sharp growth and attests to the growing scientific interest in the relationship between climate change, sustainable urban water management, and urban planning.

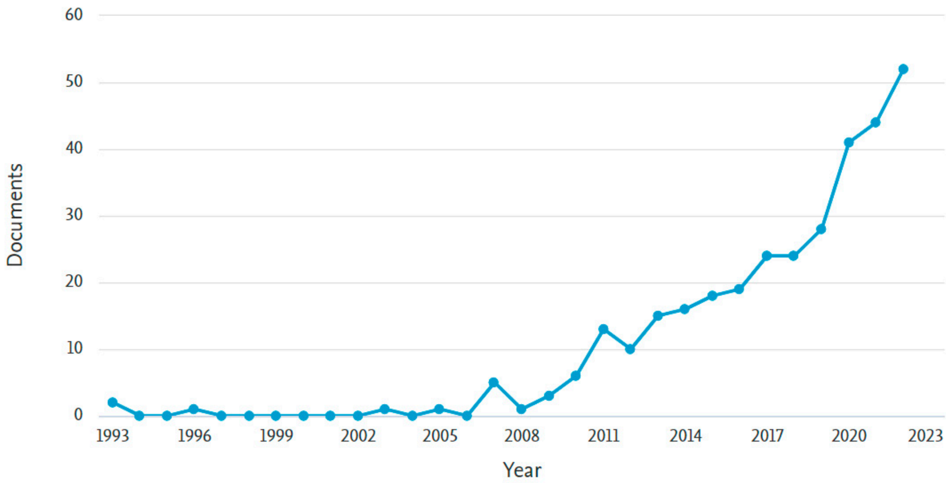

Figure 2. Annual distribution of the number of articles after Scopus search for the selected keywords and criteria. Figure source: Scopus.

The geographical distribution of articles and case studies, represented in Figure 3a,b, shows a prevalence of the Netherlands, USA, Australia, China, and the UK, which confirms the pancontinental nature of interest in this theme. That said, a joint analysis of those figures also suggests that most of the articles focus on the authors' territory, being the majority from developed countries, which makes it possible to infer that underdeveloped countries still need to be subject to such an in-depth analysis. The contribution of authors from Israel and Singapore should also be underlined, especially considering the perspective of the size of each of these countries, although it is known that these two countries are among the ones that faced severe water scarcity.

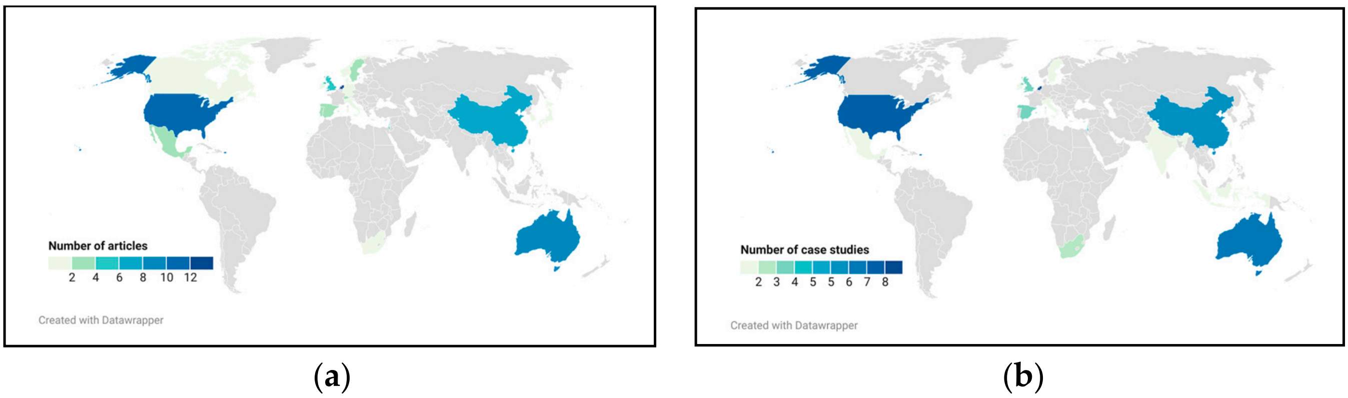

Figure 3. (**a**) Geographical distribution of the articles considered in this article (1st author). Figure source: Datawrapper; (**b**) Geographical distribution of the case studies considered in the article. Figure source: Datawrapper.

3.2. Concepts of Sustainable Water Management in Cities

3.2.1. From the Scientific Literature

With the concept of SUWM, some authors [31,32] associate decentralisation, resource efficiency, and sustainability as critical factors. Also associated with this concept are technical configurations, such as the collection and reuse of rainwater [33], "grey water" recycling [34,35], design of "blue" and "green" infrastructures [36,37], and the optimisation of water consumption by the final consumer [38]. Within the concept of SUWM, other urban water cycle management concepts/frameworks are included, such as integrated urban water management (IUWM), water-sensitive cities, low-impact development (LID), sustainable urban drainage systems (SUDS), and Sponge Cities, to mention the most relevant. Despite their complementarity, other innovative city concepts primarily based on digital development and technology, such as those related to smart cities, will not be studied here since water management, sustainability, and urban planning are not at their core [39].

All these concepts, presented in Table 2, seek to respond to the new challenges by integrating the management of water resources with the drivers that most affect their availability and ecological status: climate change, population growth, and increasing urbanisation.

Table 2. Key sustainability concepts associated with water management and the new paradigms in the 21st century.

Concept	Definition	Origin
Low-Impact Development (LID) 1977 [40]	- *The original intent of LID was to achieve a 'natural' hydrology by use of site layout and integrated control measures. Natural hydrology referred to a site's balance of pre-development runoff, infiltration, and evapotranspiration volumes, achieved through a "functionally equivalent hydrologic landscape"* ([41], p. 3) - *The LID practice is an integrated watershed management strategy, which provides natural retention, treatment, and source protection capabilities.* - *It utilises natural processes to capture, treat, absorb, and infiltrate stormwater runoff that has increased in peak rate and volume with more pollutant contents* ([42], p. 1).	USA New Zealand (LIDUD)
Integrated Urban Water Management (IUWM) 1995 [43]	- *IUWM promotes a coordinated planning approach to drinking water, wastewater, and stormwater services that takes into consideration the broader implications of sustainable development, including energy demand, greenhouse gas emissions, solid waste generation, nutrient losses, life cycle costs, and community acceptability* ([44], p. 2) - *IUWM provides cities with a new framework for planning, designing, and managing urban water systems. An IUWM perspective enables all stakeholders to look at the urban water system holistically, as an integrated, cooperative venture, and together supply the capacity to predict the impacts of interventions across broad resource management units. By doing so, the framework facilitates the development of innovative solutions for urban water management and the prioritisation of resources* ([45] p. 58).	-

Table 2. *Cont.*

Concept	Definition	Origin
Water-Sensitive Urban Design (WSUD) 1996 [46]	- Lloyd et al. ([47], p. 2) describe WSUD as a *"philosophical approach to urban planning and design that aims to minimise the hydrological impacts of urban development on the surrounding environment. Stormwater management is a subset of WSUD directed at providing flood control, flow management, water quality improvements and opportunities to harvest stormwater to supplement mains water for non-potable uses"*. - *Water-sensitive urban design (WSUD) is supported by an underlying value of providing urban water services in a manner that considers the site-specific opportunities and limitations of development to provide water services in a way that protects and enhances local hydrological and ecological integrity. WSUD considers all aspects of the urban water cycle as a valuable resource. Incorporating WSUD in urban developments can also improve resilience to reduced yield from conventional water supply catchments due to potential climate change impacts* ([44], p. 2).	Australia
Sustainable Urban Drainage Systems (SUDS) 2000 [48]	- *SUDS consist of a range of technologies and techniques used to drain stormwater/surface water in a manner that is (arguably) more sustainable than conventional solutions. They are based on the philosophy of replicating, as closely as possible, the natural pre-development drainage from a site, consistent with the previously described principles behind LID.* - *Typically, SUDS are configured as a sequence of stormwater practices and technologies that work together to form a management train* ([41], p. 5). - *(. . .) SUDS can improve the sustainable management of water by replicating natural drainage patterns; reducing the peak flows, volume, and frequency of flows into watercourses from developed sites; removing pollutants from diffuse pollutant sources; and increasing the potential for rainwater harvesting. Consequently, SUDS can reduce downstream flooding risks, improve water quality, recharge groundwater and maintain base flows, reduce potable water demand, and improve local amenities through the provision of public open space and wildlife habitat* ([23], p. 7).	UK
Sustainable Urban Water Management (SUWM) 2008 [49,50]	- *SUWM concepts can be considered the next step in this co-evolution and reflect growing concerns over community wellbeing (rather than just public health), ecological health, and sustainable development, all of which can be collectively labelled as 'green' issues (. . .) SUWM reflects a generalised goal to manage the urban water cycle to produce more benefits than traditional approaches have delivered* ([31], p. 2). - *SUWM is advocated by an increasing number of scholars as an alternative paradigm to traditional water infrastructure and approaches, which can address the complex challenges facing urban water management. (. . .) SUWM is an umbrella concept that encapsulates the concepts of 'integrated urban water management' and "water-sensitive urban design" (WSUD)* ([51], p. 1).	-

Table 2. *Cont.*

Concept	Definition	Origin
Sponge City 2014 [52]	- *The Sponge City concept aims to (i) adopt and develop LID concepts, which improve effective control of urban peak runoff, and to temporarily store, recycle, and purify stormwater; (ii) upgrade the traditional drainage systems using more flood-resilient infrastructure (e.g., construction of underground water storage tanks and tunnels) and to increase current drainage protection standards using LID systems to offset peak discharges and reduce excess stormwater; and (iii) to integrate natural water bodies (such as wetlands and lakes) and encourage multi-functional objectives within drainage design (such as enhancing ecosystem services) whilst providing additional artificial water bodies and green spaces to provide higher amenity value* ([22], p. 2). - *(. . .) "sponge city" concept (. . .) represents a new urban development mode that is intended to manage effectively urban rainwater. This concept gives priority to protection and remediation of natural environments in urban planning and construction to ensure their ecosystem service function of water conservation. "Sponge city" vividly describes an urban environment that is devoted to finding ecologically suitable alternatives to transform urban infrastructures into green infrastructures so they could capture, control and reuse precipitation in a useful, ecologically sound way* ([53], p. 1).	China

3.2.2. From Grey Literature

The most structured recommendations in grey literature on how to address climate change in the design of cities, their relationship to water, and in some cases with risk, have been promoted through organisations such as the International Water Association (IWA (International Water Association), 2016), the World Bank [26,54], or the United Nations [28], among others. They are presented in the form of multi-stage frameworks that help build the response of cities and territories to the challenges of climate change, particularly in water systems. The methodologies and practices that stand out from the grey literature are shown in Table 3:

Table 3. Structured recommendations from grey literature.

Publication/ References	Main Recommendations	Case Studies Referred to in the Publications
United Nations Educational, Scientific and Cultural Organization (UNESCO) Climate Risk Informed Decision Analysis (CRIDA) [28]	Publication extract: *"(. . .) the UNESCO International Hydrological Programme presents, therefore, the Climate Risk Informed Decision Analysis (CRIDA). This approach provides a crucial framework to enable water managers and policy makers to assess the impact of climate uncertainty and change on their water resources and work towards effective adaptation strategies.* *This multi-step process embraces a participatory, bottom-up approach to identify water security hazards, and is sensitive to indigenous and gender-related water vulnerabilities.* *By engaging local communities in the design of the analysis, the information provided by scientific modelling and climate analysis can be tailored and thus provide more useful answers to the challenges they are facing. They are also providing a more informed starting point to assess the different options for adaptation, and design robust adaptation pathways, in line with the local needs.* *The CRIDA approach advocates hereby to move away from the "one size fits all" approach, and to pursue locally embedded solutions to the specific threats to water insecurity due to climate and other global changes (. . .)"* ([28], p. 9). Synthesis: It is a framework that considers a risk analysis and how it should be managed when a given system is confronted with climate change. It seeks to develop participatory adaptation methodologies involving different stakeholders and adapted to each location from a *bottom-up* perspective.	Colombo Bangkok Philippines Udon Thani Colombia Chile Mexico Guayaquil Zambia Sweden Rhine river Lake Ontario California

Table 3. *Cont.*

Publication/ References	Main Recommendations	Case Studies Referred to in the Publications
World Bank Water in Circular Economy and Resilience (WICER) [54]	Publication extract: *"WICER aims to promote a paradigm shift in the water sector. The shift involves moving away from linear thinking in the way we plan, design, and operate water infrastructure in urban settings towards a circular and resilient approach (. . .) Applying the WICER framework provides environmental benefits, as well as social, economic, and financial benefits. It is also a condition for achieving several of the global Sustainable Development Goals (SDGs)* ([54], p. 43). Synthesis: This report aims to promote a common understanding of the definition and applications of circular economy principles and resilience in the urban water sector. It presents a framework to guide practitioners who are incorporating the principles in policies and strategies, planning, investment prioritisation, and design and operations to achieve three main outcomes: (1) deliver resilient and inclusive services; (2) design out waste and pollution, and (3) preserve and regenerate natural systems. These will ultimately improve livelihoods while valuing water resources and the environment. These outcomes are then deployed into three action plans each. It also states that cities and water utilities will only achieve a fully circular and resilient water system with the appropriate policy, institutional, and regulatory framework in place. It shows examples that investments in circular and resilient systems yield economic and financial payoffs and that the WICER framework could help utilities attract private-sector finance. To avoid being locked into linear and inefficient systems, low- and middle-income countries should also consider applying the WICER framework to design and implement circular and resilient water systems from the outset.	Durban Bogota River Chennai São Paulo Monclova Mostar Cali Ridgewood Santiago Atotonilco Indonesia Phnom Penh New Cairo S. Luis Potosi Nagpur Dakar Lingyuan Arequipa North Gaza
International Water Association The IWA Principles for Water-Wise cities [55]	Publication extract: *"Water-wise" behaviour means that leadership culture, governance arrangements, professional capacity, and innovative technology are all aligned with the objective of maximising sustainable urban water outcomes. Sustainable urban water management means that all water within the city (including reservoir and aquifer water, desalinated water, recycled water, and stormwater) is managed in a way that recognises the connection between services, urban design, and the basin, with an approach that maximises the achievement of urban liveability outcomes, and resilience to unexpected social, economic, or bio-physical shocks, while replenishing the environment."* ([55], p. 2) Synthesis: The ultimate goal of the principles presented above is to encourage collaborative action, underpinned by a shared vision, so that local governments, urban professionals, and individuals actively engage in addressing and finding solutions for managing all waters of the city. From 5 building blocks and 4 levels of action, the 17 Principles are grouped into four categories: regenerative water services, water-sensitive urban design, basin-connected cities, and water-wise communities. Water-wise communities will use the building blocks to put the principles into action.	Amsterdam Berlin Brisbane Copenhagen Dakar Gothenburg Kampala Kunshan Lyon Melbourne Perth Shenzen Singapore Sydney Xi'an

This sub-section presented the status quo of the world's best-structured practical references in this field. It aimed to outline if their approaches complement those of the scientific literature referred to in the previous section. Further research could also help to assess how the scientific literature validates the grey literature.

3.3. Approaches to Climate Change Adaptation of Water Utilities and City Planning

Since the 19th century, water infrastructure has been centrally built to address hygiene and health issues, significantly reducing diseases and increasing health [56]. Centralised systems, the norm in cities, are characterised by extensive treatment, distribution, and collection facilities for treatment that connect distant points of origin/rejection and their final consumers [57]. Most developed countries spend between 1% and 6% of their annual GDP on centralised systems [58], resulting in substantial "sunken costs" and total dependence on water services (by nature with great inertia). Consequently, they face a blocking situation in which transforming alternatives for water management encounter barriers to entry [59].

These very centralised systems are based on mainly buried infrastructures whose main objective is to reach the water to citizens in quality and quantity, drain and treat the effluents generated, and drive rainwater as quickly as possible out of urban areas. Often, these infrastructures lead water from distant regions to the populations that need it through systems that favour the reliability and quality of the water supplied [31]. Similarly, treated effluents are often rejected from their place of production in large wastewater treatment plants. The dimensioning of these infrastructures is made for a distant design horizon with high initial sunken costs [10], which, in most cases, implies large tariffs for the first generations that use them and an idle capacity for at least the first years of activity [10]. This means a consequent waste of financial and operational resources, considering the need to "move" high water resources out of their natural "habitat", with impacts that go far beyond your place of consumption [31].

On the one hand, floods often involve the routing (undue if in separative networks) of rainwater to wastewater collectors, thus implying discharge into the water environment and in an uncontrolled form of crude effluent, more or less diluted. Besides this impact on the environment, floods also entail increasing human and property damage to which the current paradigm cannot respond, not only in developing countries (for instance, Mozambique and Pakistan) but also in developed countries, of which the 2021 floods in Germany are a recent example [60]. On the other hand, it is neither technical nor economically feasible [10,19]) to size wastewater and rainwater infrastructure for all extreme situations that potentially occur.

Concerning water scarcity, despite growing awareness of the effects of climate change, the transformative process of water management to include new sources (such as water reuse, rain harvesting, or desalination) or new conceptions (such as decentralised systems, green and blue infrastructures, etc.) is confronted with several obstacles that still lead to some inertia [32]. It should be said, however, that this latent stagnation is primarily presented by the incumbents, which present, among others, barriers to the implementation of innovative measures such as [32]: greater reliability (general) of centralised water systems, potentially lower costs of centralised systems (more significant economies of scale), perception of greater risk to public health by consumers, legislation not yet fully adequate for water reuse, uncertainties regarding the governance of the different systems in the future, and the lack of motivation in the entities that manage the status quo. This "lock-in" effect [61,62] is associated with apparent economies of scale, progress in the "learning curve", confidence in existing technologies, and network economies (agents using the same technology as their peers) [31], which translates into a barrier to innovation and the entry of more sustainable systems, perpetuating the incumbent.

However, there are also crucial motivations that lead to transformative processes in the relationship between urban water management and urban planning, such as [32,63,64]: the need to resize cities according to the variation of their population and consequent increase in consumption; public perception of the waste of the use of drinking water for irrigation, flushing of toilets, and washes; climate change, with a particular focus on capturing/deferring rainwater runoff and managing water scarcity; food security, as the lack of water, together with the degradation of agricultural land, leads to a reduction in agricultural productivity, which in turn leads to lower incomes and food availability [6,65]; increased consumption and decreased availability motivated by the average and "peak" increase in temperatures; sensitivity to phenomena such as self-sufficiency and the circularity of the economy. Naturally, in very concrete geographies, extreme phenomena of lack or excess of water are already the biggest catalysts for this paradigm shift, such as the cases of Israel, China, Australia, California, and Singapore, to report the most studied [66–68]. Thus, even in well-established and proven systems, the need for reinvestment, the urgent response to climate change, and the dynamics of urban expansion force a paradigm shift, which becomes necessary, both in underdeveloped countries and in developed countries.

For their part, in underdeveloped countries, in addition to drivers related to climate change and population growth, high rates of urban growth, poor trust in institutions [69], and uncertainty about city planning, combined with a lack of initial capital and high discount rates, lead to the trend of investing in rapid implementation solutions and in turn to a strong tendency to avoid significant investments in infrastructure [70].

The progressive hybridisation of centralised and decentralised systems has been reported as the most likely trend of implementation, combining the reliability and financial sustainability of centralised systems, so-called conventional, with the need to adapt cities to climate and demographic change, thus ensuring greater resilience. In this context, there is room for more consolidated studies, particularly about both levels' systemic and parallel functioning [32]. As such, the challenges presented above require different approaches and paradigms.

The way literature faces these challenges can unfold systematically in the following vectors: operational, organisational, institutional, behavioural, economical, technological, and urban planning.

Concerning the operational vector, the scientific literature points towards the definition of strategies to save water, reduce losses [10], minimise undue inflows to urban systems, and separate the sanitation of wastewater and rainwater [33,42] and the use of stored rainwater in periods of lower rainfall [71], either in a single-family management analysis [33] or in a city-level or basin-level approach [71,72]. Of course, some of these operational interventions must be integrated with the necessary investments corresponding to the economic and technological vectors.

At the organisational vector, the tendency referred to in the literature is for decentralising infrastructures and systems, corresponding to their greater spraying. The challenge arises regarding their management—in the local community, municipal, or WSPs—and, in any case, how centralised and open to citizen participation is. Questions are raised, as to how the "water decentralised infrastructures" should be created, given the technologically premature state of the proposed solutions and information regarding exploration costs, monitoring of their performance, and diffuse responsibility regarding their current management [31,44].

At the institutional level, efforts focus on sharing objectives and knowledge, usually with very flexible approaches, involving various stakeholders at national, regional, and local decision-making levels. At the economic vector, no direct savings in technical solutions related to sustainable water management are evident [31], especially considering the energy and operating and maintenance costs accompanying solutions such as desalination [35], rainwater harvesting [33,73], or reused water [32,74], where the "scale" factor is essential.

Concerning the behaviour of the final consumer, studies have been presented in Israel that correlate their perception of those reuses with their level of treatment, their possibility of use, and other variables, such as education and age [68,75]. The desire to consume alternative sources of water and the way the message is passed are fundamental aspects of its implementation [68,76]. However, some 13% of the consumers in a study conducted in the United States rejected the use of recycled water, depreciatingly called "from the toilet to tap" by those opposing it [77].

At the technological vector, the main trends concerning the challenges in the urban water sector for the 21st century are related to (i) the increased use of alternative sources of water, namely the reuse of rainwater [33,62,73,78], the reuse of water (direct or indirect), and desalination and the new technologies related to it that arise (Larsen et al., 2016); (ii) the "buffering" of extreme phenomena (usually related to floods) [8,42,62,79] in the search for more sustainable solutions with positive environmental externalities [35,68,80–82], such as Sponge Cities in China, greenfield expansions in Australia or redevelopment in the Netherlands [8,22,53,83]; and (iii) the application of information technologies to the planning of the urban cycle of water and cities [79,84,85]. Considering the various drivers referred to above, which influence the relationship between the sustainability of the management of urban water resources in the face of the challenges of climate change, population growth, and increasing urbanisation, growing literature is addressing the use of artificial intelligence to integrate the diversity of inputs. This literature seeks to integrate more technical and socio-economic baseline data, such as spatial planning, localisation of water infrastructures, impermeable surfaces, green areas, and green roof areas, among many others [38,84] to understand the practical implications that the future provides, depending on the simulated scenario. In a more focused way, several studies model and project the various possibilities of water reuse [86], rainwater reuse [73], or the behaviour of watersheds in extreme situations [87], among many others.

Finally, the scientific literature related to urban planning focuses on how positive externalities can be obtained in the pursuit of sustainable solutions that allow cities to tackle climate change ([20,22,30,71,88]. These analyses have focused on the preparation of cities for the management of water retaining [18,20] by defining the constructive details to be implemented in public/private infrastructures (porous pavements, green roofs, etc.) [42,64], by xeriscaping [87], through integrative interventions at the neighbourhood level [83,84], by the adaptation of the blueprint of cities to help landscape management in prioritising urban development strategies in the water-energy nexus [87] and the significant transformations of expansion or adaptation of cities considering rainwater management [71]. London is a paradigmatic example in how it defines water neutrality as a concept to frame the water stress in cities, integrating spatial data with an integrated urban water management model; this holistic, systemic design framework is designated CityPlan-Water [38]. In Table 4 we summarize the vectors presented in Figure 4 with the approaches to tackle climate change and urbanisation in the water sector.

Table 4. Synthesis of the approaches to tackle climate change and urbanisation in the water sector.

Vectors	Approaches	Examples
Operational	Strategies to save water and reduce losses	[10]
	Minimise undue runoff to sewer systems	[73]
	Separate sanitation of rainwater and wastewater	[33,42,76]
	Mindset towards the use of reserved rainwater in periods of lower rainfall	[33,71,72]
Organisational	Lack of knowledge	[24,25]
	Adaptation needs (WSP)	[31,44]
	Decentralisation vs Centralisation	[29,31,76]
	(Diffused) Responsibility	[44]
	Circular Economy	[15]
Institutional	Inter-organisational practices	[89–91]
	Water and land management communication	[20]
	Governance of adaptation	[90,92,93]
Economical	Financial (dis)advantages	[31]
	Costs and scale factor	[33,73,74]
	Last resort systems cost	[76,94]
	Food security	[6,65]
Behavioural	The context for the acceptance of water reuse	[68,75]
	Communication strategies for water reuse	[68,76]
Technological	Reuse of rainwater	[33,61,62,73,78]
	Reuse of water (direct or indirect)	[35,74,80,86,95–97]
	Watershed behaviour	[87]
	Buffering of extreme phenomena (floods)	[33,62,79,85]
	Positive externalities	[22,53,76,98]
	Information technology	[79,84,85,87,99]
Urban planning	Symbiosis of adaptation to climate change in cities and the water sector	[20,22,30,71,88]
	Interventions at the neighbourhood level	[83,84]
	Landscape management	[87]
	Major adaptations in cities	[38,71]
	Multilevel adaptation	[93]

The table above shows the main references found for each vector, outlining the limited number of those dealing with the relationship between the entities that manage the water services and the territory.

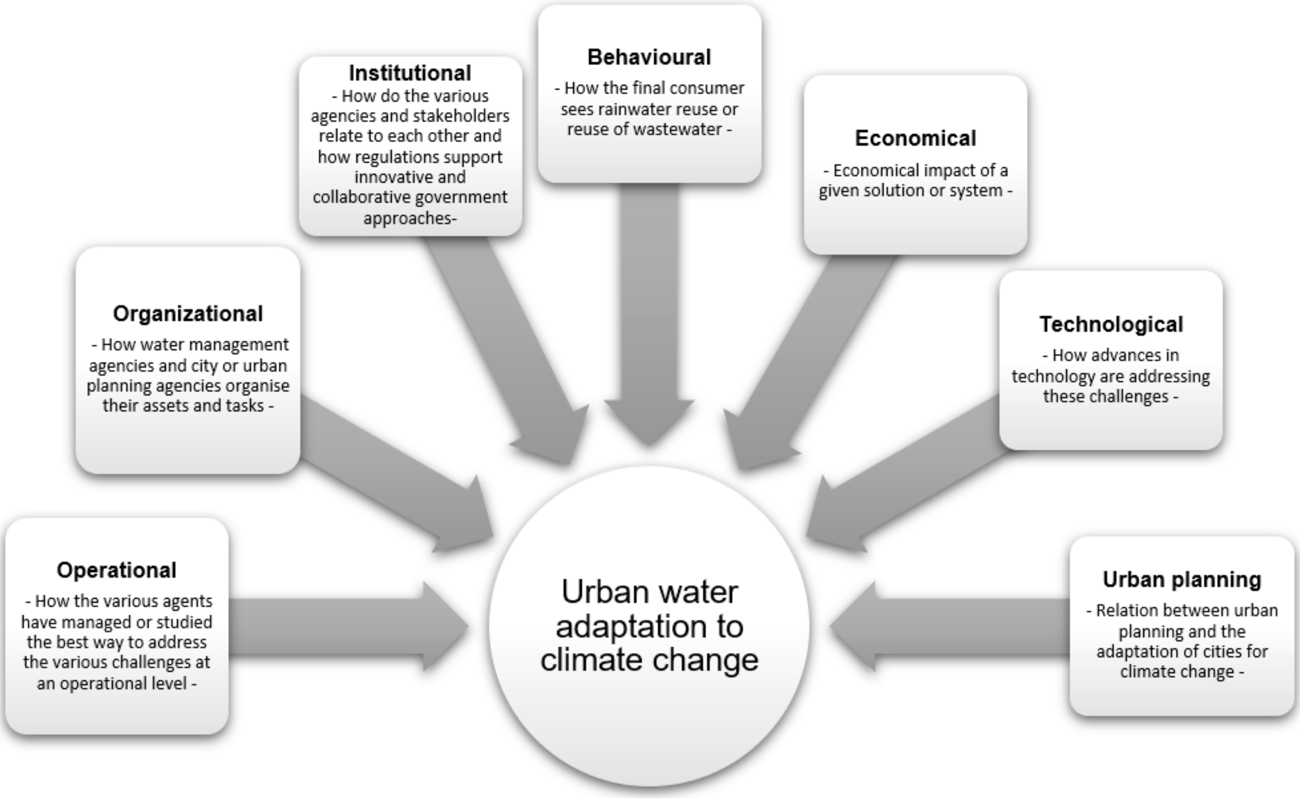

Figure 4. Main vectors contributing to the urban water management adaptation to climate change, according to the literature review.

4. Discussion

Considering the results mentioned above, several issues can be highlighted concerning the relationship between sustainable water management, urban planning, and climate change. In fact, despite the lack of practical implementation that does not yet follow the diversity of existing scientific literature on the sustainable management of the urban water cycle [38], it already presents a set of learnings/outcomes and gaps that allow us to perceive the main insights and the gaps to be filled.

One conclusion to be withdrawn from the outset is that the most significant innovations or need for innovation are mainly at the organisational and economic vectors and in the relationship between the various stakeholders and citizens/consumers and not so much in terms of technological development since the main drivers for change still arise in the paradigm shift from centralised to decentralised systems and how to share their management with the other stakeholders, including entities that manage the territory. Although there is a trend in the literature towards responding to climate change through decentralised systems, some of the best examples of success in adapting to climate change in the water supply sector, especially in terms of water reuse, occur using concepts of centralised systems, such as Singapore, Israel, or Southern California in the US.

Of course, in situations where redundancy exists, i.e., where centralised infrastructure remains a "last resort", there may be double pricing to sustain the sunken costs related to that system and the capital and operating cost tariffs associated with more sustainable methods. There is a need for a broader cost–benefit analysis involving not only the financial aspects but also the positive/negative externalities resulting from the implementation of more "sustainable systems" [76,94].

It is important to remark that the relationship between urban planning, WSPs, and climate change has also focused on flood control and less on water supply. There is, therefore, a gap in the need for scientific development [30,100]. This gap significantly increases when it comes to the integrated management of both "too much" or "too little" water, i.e., flood control and water supply.

For that matter, WSPs are facing increasing challenges in terms of water availability, management of consumption patterns, and the need for increased efficiency, which are alternatives to be developed to address the problem of lack of water [62], here still in the context of water directly collected from the water environment.

The planning of water infrastructures tends to be subordinate dweller to the planning of the territory [20] in a way that, in addition to being technically challenging, has also demonstrated other types of problems, such as complex collaboration in the face of more controversial situations of land use. On the other hand, the unavailability of staff in smaller locations and a level of diffuse responsibilities within and between each side, urban planning and WSPs, tend to hinder the necessary convergence. [20]. Adapting to a changing climate requires the collaboration of the disciplines of spatial planning and urban water supply management [30].

Many arguments and practices associated with concrete cases of articulation between WSPs and those that manage the territory can also be applied to the water supply strand. Consolidating a projection of the future—a practice to which urban planning is dedicated—with the projection of climate change is pointed out as being the way forward, to which the necessary articulation with the drainage and water supply strands of the WSPs is added.

Some of the barriers to overcome in the water sector are related to the "lock-in" effect related to the already mentioned inertia derived from the sector, often resonating on buried infrastructure with an extensive lifetime and high capital costs. On the other hand, it is a sector traditionally averse to innovation [10,76], both technical and operational [31]. The main insights and gaps that stand out from the literature are presented in Table 5, following Figure 4.

Table 5. Synthesis of the main insights and gaps that arise from the literature review.

Vectors	Insights and Gaps
Operational	The pluri-functionality of some installations (e.g., flood control and management, reuse of waters) contributes to a dispersion of the objectives to be achieved, often competing with each other or not taking advantage of their synergies [44].
	Regulatory changes and poor anticipation of operating costs are some of the risks most evidenced by experts dealing with water reuse [81].
	Grey water constitutes 50–80% of the total household wastewater produced, which enhances its future use after treatment [74,101].
	The decentralisation of systems can present great advantages in areas where, under "business as usual" conditions, it would be necessary to expand a centralised system, thus contributing to a more resilient system with less investment in capital, thus enhancing greater naturalisation of the same [31].
	Given the lock-in effect, the trend will be the coexistence of centralised and decentralised systems, thus operating a gradual change between both philosophies and a path leading to their hybridisation. The management of water demand, and not only the increase in its supply, can contribute decisively to the minimisation of the risk of water scarcity [31,83,99].

Table 5. *Cont.*

Vectors	Insights and Gaps
Organisational	Theoretical studies are presented that present ways for the adaptation of WSPs in different contexts and how their adaptability and learning are essential to meet the challenge of climate change [102].
	This adaptation can be facilitated by political and legislative measures [103].
	Reference [103] also demonstrated through an intersectoral study conducted in the UK that the water supply and flood control sectors are those in which at the institutional level, there was more significant activity to adapt to climate change, often from a top-down perspective (above the local level), with climate change triggers (actual or perished) and legislation, despite the fact that the need for interventions on the ground have greater difficulty in implementing if they are only motivated by climate change.
	There is a lack of deepening between sustainable urban water management measures, citizens' perception and socio-economic issues, and the use of the territory [30,63,76].
	There is a need for analyses that realise the possibilities of a relationship between sectoral measures of water resilience with the components of business and political decisions and studies relating to the relationship between conventional and decentralised water resource management systems [104].
	There is a gap in the knowledge about the implementation of the resilience of water systems more qualitatively and less quantitatively towards a more in-depth risk assessment and the relationship between water resilience systems—designated at flood level—and water supply, transport, energy, and waste collection systems [105].
	There is a need for more consolidated studies and reports on how to operate and maintain hybrid systems (centralised and decentralised) and how to define the attribution of responsibilities [76].
Institutional	The planning of the territory will tend to be more challenging and complex in the future, not only motivated by an entity—municipality or managing body of the water service provider—but more integrated towards closer interests, which may even converge to new structures or allocation of responsibilities in the management of public services [104]. Bearing in mind the need to create sustainable urban and regional planning practices, the articulation between institutions and spatial planning policies and water management tends to become one of the central concerns [93]. Given the constraints of articulating rigid institutional structures, informal networking structures are beginning to appear between different interests that fill the gaps between the different, and often conflicting, official organisations [91].
Economical	In most cases, a financial analysis, pure and complex, that is, intending to obtain a net present value (NPV) as a central element for the viability of a given project, will not result in an advantage of SUWM systems, and there is a need to converge to a more holistic approach that takes into account the minimisation of the risk inherent to phenomena of scarcity or excess water, the creation of leisure spaces, the minimisation of heat islands phenomena, increased resilience and the potential reuse of captured/reused water [31,83].
	There is a need for a deepening of knowledge that further characterises the vectors that contribute to a more comprehensive "value" of a given SUWM solution [31,106].

Table 5. *Cont.*

Vectors	Insights and Gaps
	Several analyses are confronted with the need to consider social, environmental, and economic factors together, and not just a financial analysis that can often not be shown to be favourable in determining the solution whose positive externalities are too evident [76,80].
	The use of rainwater harvesting systems can also contribute to a decrease in costs with public drainage systems. A cost–benefit analysis that highlights the scale of these benefits is necessary [33].
Behavioural	Among the reasons for some resistance on the part of consumers to the use of recycled water are real or assumed health risks, mistrust of authorities responsible for managing water and minimising health risks, and disgust with the idea often referred to as the "yuck factor". There are even cases where, although it is proven that treated water is purer than bottled water or tap water, due to the "yuck factor" acceptance is nil by some consumers. There is also resistance on the part of consumers to have direct contact with reused water, especially if there is a perception of health risks [75].
	The level of resistance often has to do with the availability of water and its cost [66].
	In Singapore, a positive press speech and a well-founded sense of safety in the face of water reuse, given the use of state-of-the-art and redundant technology, were essential aspects for the community's good acceptance of reused water, called NEWater, which is used for indirect potable use, to be introduced into raw water reservoirs. The blended water undergoes naturalisation and further treatment in conventional waterworks to create drinking water. A similar situation occurs in Southern California [68,107]
Technological	Water treatment for reuse purposes converges on increasingly advanced technologies, including membrane bioreactors (MBRs) or MBRs combined with forward osmose (FO) towards greater energy efficiency, of which Singapore is the gold standard in integrating water reuse at the scale of a large city [68,74].
	Typically, the most economical reuse of grey water is that associated with showers and washbasins, and less than associated with kitchen stalls and washing machines, considering its higher content in fats and detergents. This knowledge can be necessary in the definition of internal drainage networks of buildings considering the reuse of grey waters [23,74].
	The main forms of water reuse occur through its direct reuse (after treatment), adequate discharge in water medium with characteristics adjusted to the receiving medium, or through the recharge of the water environment through which water will be obtained again for consumption. In addition to saving the water balance, they also make it possible to know the reused water available for future use (depending on consumption) and the possibility of using nutrients in agriculture/irrigation (depending on the type of treatment) [72,80].
	There is still ignorance about the effects and amount of micropollutants of direct recycled water in humans, so the tendency will still be to avoid its use for consumption or cooking [35].
	The reuse of rainwater is not (directly) economically viable on a small scale (isolated dwellings or small condominiums), as concluded from studies carried out in Spain and the Netherlands [33,73].
	Desalination is even more expensive than water reuse, and both are more expensive than direct capture in the water environment [35,68]. Even so, technological development, both in terms of performance and energy consumption, has been presenting solutions and systems that are very promising in the fields of desalination and water reuse [95–97,108].

Table 5. *Cont.*

Vectors	Insights and Gaps
	There is a panoply of technical solutions that contribute in a proven way. For flood damnation and uncontrolled runoff in cities, such as (bioretention) system sites, artificial wetland sites, infiltration-only systems, permeable pavements, green roofs, artificial ponds, bioswales). Some solutions are even quick-fix implementations contributing to a fast and economic control of the flow, such as draining pavements, as studied in the cases of Sponge Cities and Parma [22,44].
	There is a much greater reference to solutions for flood control than to the reuse of water or rainwater collection [30].
	There is a need to deepen knowledge of the relationship between urban planning, climate change, and water use using IT tools [99].
Urban planning	The instruments of urban planning and governance of cities are essential for implementing a strategy of greater water resilience, bringing both conceptually and physically closer to the various actors that can contribute to its realisation. Territory planning can even act as an instrument to facilitate the implementation of these measures [30,63].
	The articulation between urban planning and urban water management can be materialised, for example, by imposing water reuse measures in multi-purpose projects, careful location of treatment infrastructures, and reuse of "grey" waters; the location of "blue" and "green" infrastructures in a manner reconciled with the rainwater network and the conditioned approximation of industries with high consumption of service water to WWTP, among many others [32,63,74,83].
	Attention has been paid to the potential role of spatial planning in adapting to climate change in the urban water supply sector. The land use policy plays a vital role in influencing water use (demand) through planning mechanisms such as urban shape control, density, and space, as well as the recognised impact that urban development has on the water quality of the natural environment. It is not too much to stress the role that water demand should play in the planning of the territory to ensure sustainable water supply in the medium and long term [20,30,104,109,110]

The table above systematises the existing insights and gaps, constituting a basis for future integrated or vector-focused studies.

5. Conclusions

Through a literature review, this paper systematised the main concepts involving urban planning and the sustainable management of urban water (SUWM) in a context of demographic, urban, and climate change, as well as the way the scientific community interprets and tackles these challenges.

It noted an increasing concern for climate change in the context of the urban water cycle and urban management, mainly concerning flood control and not so much about cities' preparation for scarcity and water savings. Studies addressing the maximisation of water resources were also noticeable but fewer about control and management of demand. It is also perceived that the growth and adaptation of urban water systems cannot continue to be done incrementally, as it has been so far.

Knowledge deepening is required in the technical and economic evaluation of the overarching concept of SUWM systems in a way that integrates values beyond financial matters and introduces an accurate cost–benefit analysis of the solutions for society. New forms of growth, contemplating a hybridisation of systems (centralised systems that grow in a decentralised way), imply new paradigms of assessment, management, and collection of tariffs for which more consolidated knowledge is required.

Achieving synergies and economies of scale, in the panorama of cities, for systems of rainwater harvesting and water reuse are presented as themes in need of development, in particular in the way they can involve the planning of cities and their stakeholders, not only from a design perspective but also in its management, decision making, and in the preparation of the final consumer for the "new water" that can be used in a context increasingly focused on the circular economy.

The grey literature produced by international organisations has complemented the scientific literature by presenting frameworks for some of these measures that will allow the various stakeholders to consider infrastructure planning in the context of climate change according to risk.

There is also a clear need for further studies and practice on the relationship between the various actors, particularly those managing the territory and water services, towards a collaborative response to the challenges of climate change. Despite the evident constraints, yes, adapting together is possible and desirable. Further research is required, though, to clarify the design of the new institutional bridges, necessary steps, and means.

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