

Article

Bibliometric Network Analysis of “Water Systems’ Adaptation to Climate Change Uncertainties”: Concepts, Approaches, Gaps, and Opportunities

Aymen Sawassi ^{1,2}  and Roula Khadra ^{1,*}

¹ International Center for Advanced Mediterranean Agronomic Studies, Mediterranean Agronomic Institute of Bari, Via Ceglie 9, 70010 Valenzano, Italy; aymen.sawassi@uniparthenope.it

² Department of Science and Technology, Parthenope University of Naples, 80133 Naples, Italy

* Correspondence: Khadra@iamb.it

Abstract: In response to the impact of climate change and to the uncertainties associated with the various dimensions of hydrologic variability, water systems’ adaptation has risen to the top of global agendas. In accordance, identifying the additional science needed to improve our understanding of climate change and its impacts, including the scientific advances needed to improve the effectiveness of actions taken to adapt water systems, is of the utmost importance. To this aim, this research draws on a systematic bibliometric study of data, generated from the Web of Science research engine between 1990 and 2019, combined with a statistical analysis, to explore academic publication trends, and identify the strategic gaps and opportunities in global scientific research. The analysis shows the consistent level of national and international collaboration among authors, institutions, and countries, and highlights the substantial contribution of the USA and the UK to this research field. The statistical examination shows that the adaptation-informed literature on water systems remains fragmented, and predominantly centred on the framing of water resource planning and management, in addition to water engineering and infrastructure. The analysis also revealed a relatively skewed understanding of various important dimensions, such as governance, integrated water resources management, and stakeholder engagement, which are crucial for planning and implementing an efficient adaptation process. Observations reflect on the need to build water-related adaptive approaches based on a thorough understanding of potential climate uncertainties, rather than to generically address all the uncertainties in one scenario analysis. These approaches are required to combine short and longterm actions rather than considering only current and short-term measures, and to similarly associate policy and engineering, and equally consider the robustness, flexibility, reliability, and vulnerability during the planning phase.

Keywords: climate change; adaptation; water; flexible design; uncertainty; bibliometrics



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1. Introduction

Climate change is likely to aggravate threats on social, environmental, economic, and political dimensions [1,2]. These threats are illustrated either directly through the impact of thermal stress (drought, heatwaves), floods, and storms, or indirectly through changes in the ranges of disease vectors (e.g., mosquitoes), water quantity and quality, air quality, and food availability and quality, as well as the migration of populations [3,4].

The expected changes in climatic variables such as the amount, intensity, frequency, type of precipitation (e.g., snow vs. rain), temperature fluctuations, and other related hydro-climatic shocks such as a decrease in dry season flows (drought) or anticipated high-intensity precipitation (floods) are most likely to cause extreme events at the scale relevant to impact studies [5,6]. An estimated 821 million people, approximately one out of every nine people in the world, are classified as undernourished partly due to drought [7]. More than 1600 deaths may be caused annually by drought and heatwaves [7]. More than

35 million people are affected by floods [8], and more than 2 million people are displaced from their homes partly due to climate-related disasters [9]. Besides, some models predict that an increase of 40% in the number of people living in conditions of absolute water scarcity, with less than 500 cubic meters per capita per year, will be associated with only 2 °C warmings above current temperature levels [10].

Currently, around one-third of the world's population lives under physical water scarcity for at least two months of the year [7,11,12]. However, if a population faces a water scarcity induced by policies, socioeconomic relations, and/or political power, this becomes a socio-water scarcity, which is the second order of scarcity that threatens another third of the world population [11,13,14]. Consequently, societal well-being development and economic prosperity are always dependent on the constraint of water availability [10,11]. Studies have proven that agricultural production and food security would be most sensitive to water availability constraints, especially in many developing countries where the climate is already changing and economies are heavily dependent on agriculture [12–14]. Notably, arid, semi-arid, and sub-humid areas present observational evidence for changes, where all the above-mentioned threats can dramatically endanger agriculture, i.e., crop yields and livestock [15].

Since the 1970s, human actions have focused on the adaptability to these expected threats and limitations as pre-conditions for social justice, human well-being, economic development, and socio-environmental sustainability [16]. Hence, the concept of system resilience (flexibility) was introduced as the capacity to sustain human well-being and progress throughout disturbance events, uncertainties, societal changes [17,18], and to adapt to external perturbations [19–21]. New approaches were developed, advocating a more flexible, reliable, and robust water infrastructure design and planning to be able to deal with those expected risks associated with climate change [22].

As a matter of fact, flexible water infrastructure planning has the potential to manage uncertainty at a reduced cost by building less infrastructure upfront, yet enabling expansion in the future if needed [23]. However, enabling flexibility often requires substantial proactive quantification research, based on several studies and sources, to weigh the risks of rigid design, and to understand the benefits of flexible infrastructures in responding to climate change uncertainties [24].

Despite the general consensus about climate change's impact on water requirements, agricultural production, and food security, there is still a lack of knowledge about the magnitude of that impact on the users' communities. The current systems' flexibility is still unknown, the capacity of these systems to adapt to stresses induced by climate change and to absorb drastic shocks of some sudden events, i.e., floods and droughts is doubted, and the amount of research done on this issue is still unquantified.

So far, the bibliometric analysis showed to be an appropriate tool that addresses the global scientific production of academic research. The approach has been widely used in several specific fields of science: Yi-Ming Guo et al. (2019) studied the research productivity of smart cities [25]; Pauna et al. (2019) focused on microplastic in the marine ecosystem [26]; Zeshui Xu (2019) carried out a bibliometric analysis to understand the development status and trends in the field of big data [27]; Wei Li et al. (2015) assessed the global environmental assessment in a 20-year period in terms of trends of growth, international collaboration, geographic distribution of publications, and scientific research issues [28]; and Cuiqian Huai et al. (2016) used the bibliometric analysis as a tool for assessing the performance and pattern dynamics of water security research [29]. However, no attempt has been made, to the best of the authors' knowledge, to consider water systems' adaptation to climate change uncertainties.

This research draws on a systematic bibliometric study and presents a quali-quantitative analysis of data generated from the Web of Science research engine. It explores academic publication trends with the aim of identifying the strategic gaps and opportunities in the global scientific research concerning the adaptation of water systems to climate change by looking for answers to the following questions: To what extent is research addressing

water systems' adaptation to climate change? What are the dimensions and concepts that have been framed? How have water management adaptive approaches been outlined?

2. Data Source and Methodology

2.1. Data Acquisition

The search covers the English language academic literature retrieved from the Web of Science search engine, Web of Science Core Collection Database (WSCCD), within a time frame set from 1990 to 2019. Specifically, the authors searched for the terms “adaptive planning”, “uncertainty”, “resilient design”, and “climate change” using the “Related Record” option in the Web of Science database. The assumption behind Related Records searching is that articles that cite the same works have a subject relationship, regardless of whether their titles, abstracts, or keywords contain the same terms. The greater the number of cited references shared by two articles, the closer the subject relationship [30].

The resulting bibliographic database files consist of books, ordinary articles, and scientific reports. The search produced 8338 documents, a large portion of which were not relevant to our investigation due to the rise of interdisciplinary work that implies a multidimensional application of the concept of adaptation to climate change, such as Environmental Science, Water Resources Science, Meteorology, Atmospheric Sciences, and so forth.

The subject of adaptive planning under climate change uncertainties attracted several researchers working in the field of environmental science, where the investigation focused on impact assessments and strategic environmental assessments. The water engineering domain tackled adaptive water policies, adaptive planning, and the design of hydraulic infrastructures, in addition to applications in real case studies. The Meteorology Atmospheric Science focused on climate projections based on a variety of scenarios to adapt to climate change. Models and simulations were performed to assess future climate change and adaptation patterns.

In order to narrow the study to articles that explicitly connect adaptation to some aspects of water systems, the number of documents was refined to 3645 (44% of total records) by filtering the search to those within the “water resources category” of the Web of Science database.

Subsequently, the bibliographic database files were exported as Tab-delimited files- (Mac-OS or Windows) that contain “Full Record” and “Full Record and Cited References” files. The derived information from these full record files included the following: authors, titles, year of publication, keywords, subject categories, journals, organizations, and the number of citations for each article.

The analysis was performed using VOS viewer software (version 1.6.13) widely used in the literature and particularly in bibliometrics (Section 2.3).

2.2. The Bibliometric Analysis

The Bibliometric measurement methods are the proper tools to interpret and represent temporal trends and growth regarding subject categories and journals, national and international collaborations between authors, the geographic distribution of publications in terms of authors' affiliations and their citations, and some other related scientific research issues. The scientific network is based on three key analyses: the co-authorship analysis, the citation analysis, and the co-occurrence analysis (Table 1) [31].

The co-authorship analysis addresses all the links between the authors, countries, and scientific institutions associated with water-related adaptation to climate change. This analysis aims to show the level of collaboration between items and assesses the national and international cooperation between authors and countries regarding the adaptation of water systems to climate change uncertainties.

Table 1. Key bibliometric analyses applied in this study.

Types of Analyses	Description
(Authors and countries) Co-authorship	In co-authorship networks, researchers or countries are linked to each other based on the number of publications they have authored jointly.
Journals Citation	In citation networks, two items are linked if at least one cites the other.
Author's Keywords Co-occurrence	The number of co-occurrences of two keywords is the number of publications in which both keywords occur together in the title, abstract, or keywords list.

The citation analysis explores the journals that are cited for scientific papers on water-related climate change adaptation. This analysis aims to inquire to what extent the topic was discussed in various journals from diverse disciplines.

The analysis of the keywords (co-occurrence analysis) is intended to ascertain the tendency of the water systems' adaptation to climate change uncertainties research, as well as the boundaries that limit the scope of the investigated subject and involve other disciplines. In this analysis, the focus is on the keywords provided by the authors in their scientific papers, to simplify the field, the subfield, the topic, and the research issue.

2.3. The Software

VOSviewer uses bibliometric database files to construct a scientific network of items (e.g., publications, scientific journals, researchers, countries, and research organizations). Items are graphically mapped through the application of mathematical modeling. The resulting maps display the possible links or connections among the different objects of interest and classify them into clusters or groups of similar concerns. The software is compatible with dataset files exported from Web of Science, Scopus, PubMed, RIS, or Crossref JSON [31].

Basically, a link is a connection or relation between two items. Examples of links are bibliographic coupling links between publications, co-authorship links between researchers, and co-occurrence links between terms (keywords). Each link has a strength, represented by a positive numerical value. The higher this value, the stronger the link. The strength of a link may indicate the number of cited references that two publications share, the number of publications that two researchers co-authored, and the number of publications in which two terms occurred together [31].

For a given item, "the links" and "the total link strength" attributes indicate, respectively, the number of links of an item with other items and the total strength of the links of an item with other items.

An attribute value of strength, expressed with a positive numerical value, is assigned to each item and link. Items with high weights are regarded as more important than items with lower weights, while a high weight linkage reflects a strong relationship between the two concerned items [31]. Table 2 lists the terms used in this publication and reports the related definitions.

The software uses the fractional counting method in calculating the attribute value of strength. The strength of a co-authorship link is determined not only by the number of documents co-authored, but also by the total number of authors of each of the co-authored documents, and the number of citations of the document. For example, when an author has co-authored a document with n authors, each of the n co-authorship links has a strength of 1, resulting in a total strength of the n co-authorship links [31].

Table 2. The terminology involved in this study.

Term	Description
Item	The object of interest (e.g., publication, researcher, keyword, author).
Link	Connection or relation between two items (e.g., co-occurrence of keywords).
Link strength	The attribute of each link, expressed by a positive numerical value. In the case of the co-authorship link, the higher the value, the higher the number of publications the two researchers have co-authored.
Network	Set of items connected by their links.
Cluster	Sets of items included in a map. One item can belong only to one cluster.
Number of links	The number of links between an item with other items.
Total link strength	The cumulative strength of the links of an item with other items.

3. Results and Discussion

3.1. Trend Analysis

Overall, the results show a steep rise, in the past 25 years, in the number of papers dealing with water adaption to climate change, be it water systems and/or water management, in a variety of aspects. The records started to considerably grow between 2009 and 2011, with a significant jump from 77 to 145 publications. The number of documents per year, exponentially displayed in Figure 1, exhibits a sustained growth, throughout the period between 1996 and 2019, that reaches 580 documents only in the year 2019. This research shows that scientific concern is expressed as significant interest in the subject of water systems' adaptation to climate change uncertainties.

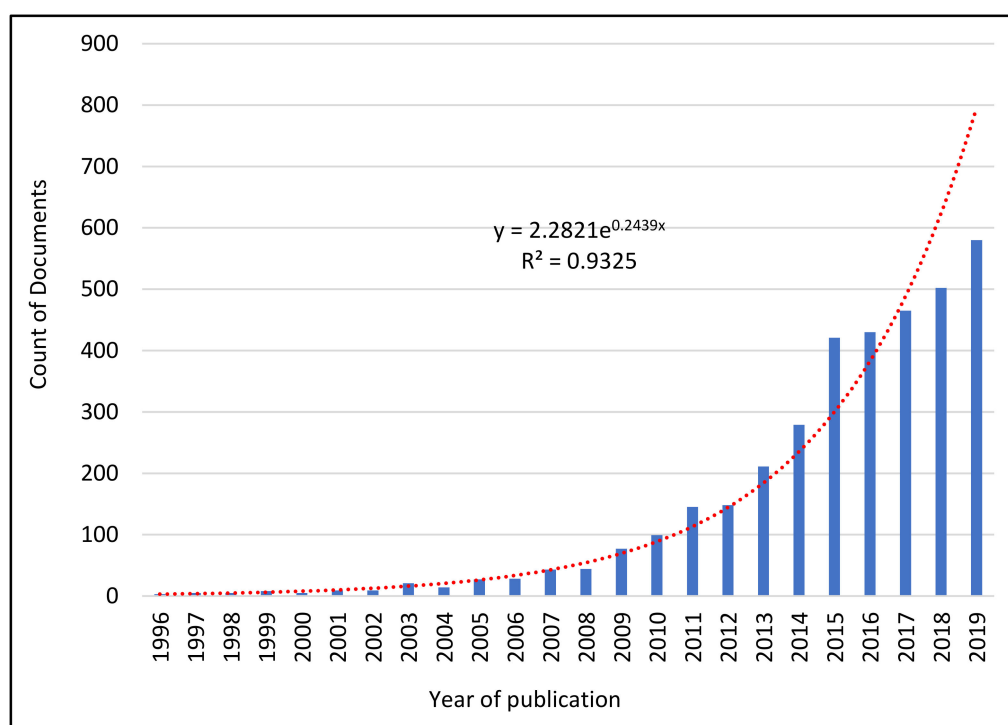


Figure 1. The annual number of publications during the period 1990–2019: the red curve represents the trendline of the growth pattern (the minimum record count appears in 1996 with 3 publications).

3.2. Citation Analysis of Journals

This analysis revealed 172 journals, of which only 68 journals eventuated in fundamental research advances with important contributions to water systems' adaptation to

climate change uncertainties (Figure 2). The analysis clearly shows that the topic has been undertaken by journals of different disciplines.

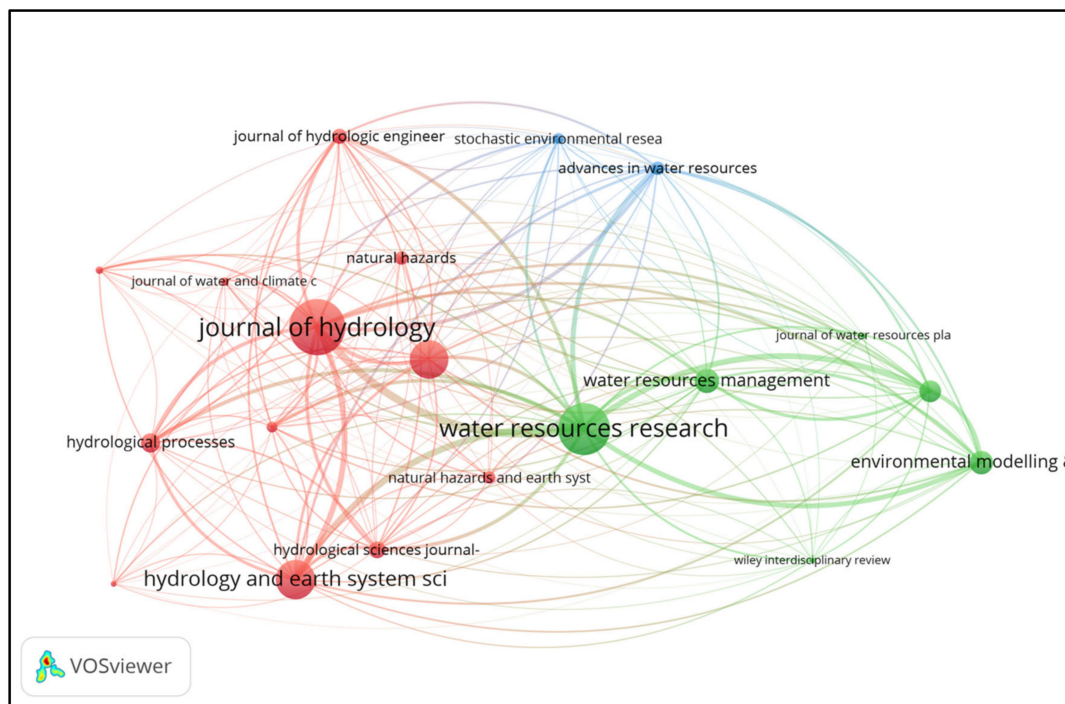


Figure 2. Network map of top 20 cited journals based on their total link strength.

The Water Resources Research Journal lead the search ranking with 388 documents and 20,187 citations, followed by the Journal of Hydrology (with 421 documents and 18,218 citations) and the Hydrology and Earth System Science Journal (with 289 documents, and 10,343 citations), and so forth. Furthermore, the analysis shows that despite the highest number of documents published in the Journal of Hydrology (421 documents), the journal is ranked only second according to its total link strength. This position might be related to the good quality of publications of the Water Resources Research Journal that are cited more.

3.3. Co-Authorship Analysis

The co-authorship analysis resulted in a network of 27,524 authors. This number was reduced to 788 by excluding documents with a large number of authors (by default, the maximum allowed number of authors per document is 25) and authors with low relevance scores. Only authors having a minimum of five publications on the topic of climate change adaptation in water systems were included. At first sight, the large number of authors who perform research related to water systems' adaptation to climate change announces a high interest in this field. Figure 3 illustrates the network map of co-authorship, which reflects the consistency level of collaboration between authors within their cluster and among other clusters. The topic has been widely tackled by means of interdisciplinary authors such as hydrologists, water engineers, geoscientists, and environmental scientists (Table 3).

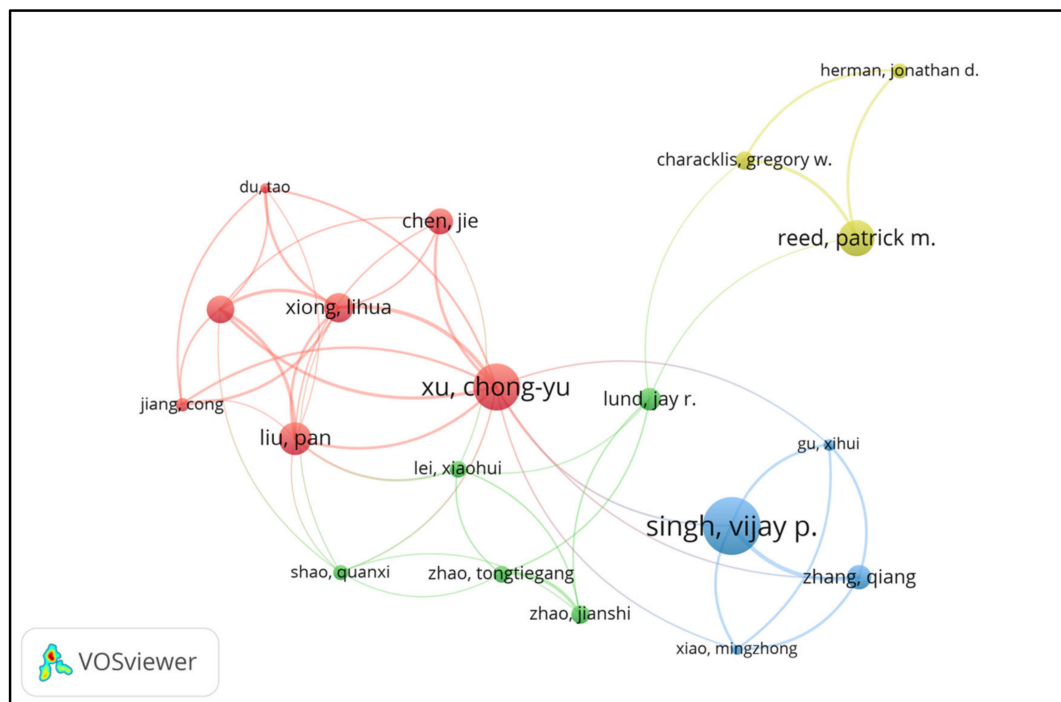


Figure 3. Network map of top 20 co-authorships based on the total link strength.

Table 3. Top 5 authors, affiliations, and research fields.

Authors	Documents	University	Department
Singh, Vijay p	36	Texas A&M University, USA	Water Engineering department
Xu, Chong-yu	29	University of Oslo, Japan	Dept of GeosciencesHydrology
Liu, Pan	20	Southeast University, China	Dept of Transportation Engineering
Xiong, Lihua	18	University of Ireland, Ireland	Dept of Hydrology and Water Resources Engineering
Guo, Shengalian	17	Wuhan University, China	Laboratory of Water Resources and Hydropower Engineering Science

3.4. Co-Occurrence Keywords Analysis

The analysis yielded 15,385 keywords. After excluding the general keywords with a low relevance score (e.g., ‘New Approach’, ‘Results’, etc.), and those with low occurrence (by default, a minimum of five occurrences of a keyword is selected, to strengthen the co-occurrence results), 961 items were finally identified. Based on the total link strength, each resulting keyword is sketched in a node, creating a network map of all keywords. Figure 4 shows the network map of the top 20 authors’ keyword co-occurrence. The size of the node reflects the keyword’s degree of importance. However, its proximity to other nodes indicates some related subjects that are frequently occurring, along with the investigated ones.

Figure 4 reports the top 20 keywords most likely representing the research hot spots over the study period (1990–2019) where: the keyword “climate change” was ranked first, followed by “uncertainty”, indicating that the climate issue is reflected in deep uncertainty about future changes [32,33]. Along with temporal evolution, the third most frequent keyword was “adaptation”, showing that adaptability to the changing future is progressively viewed as a valuable design approach concerning strategic planning in water systems [24,34].

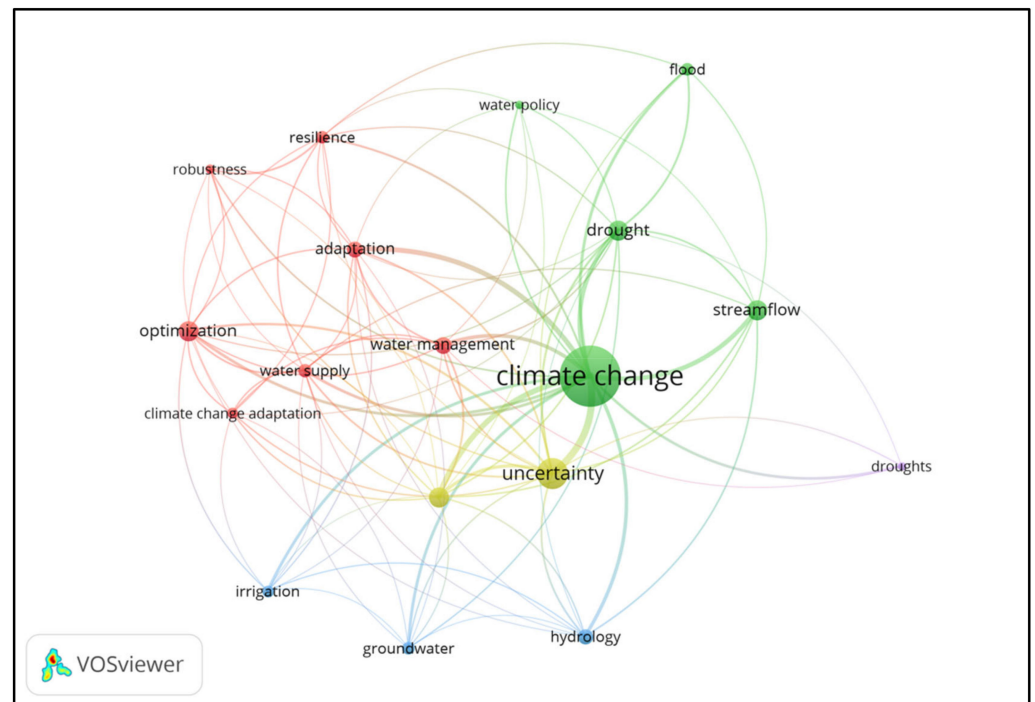


Figure 4. Top 20 frequently used author keywords during the period 1990–2019.

The increasing occurrence of keywords such as “mitigation” and “climate change adaptation” over the last two decades demonstrates the continued emphasis on these approaches. On the contrary, approaches such as “resilience” and “flexibility” are given less attention (52 and 31 documents respectively). From this perspective, there is a risk that the current adaptive water management strategies can effectively stifle potentially transformative shifts towards more infrastructure-centered thinking about water adaptation to climate change, and, at last, more resilient and flexible forms of water management.

3.4.1. The Water Dimensions, Concepts, and Scales

The quantitative analysis shows that the most prominent water dimensions integrated with the context of adaptation to climate change are “water resources management” with 1544 documents representing 43% of the total count, followed by “water planning” (537 documents), “groundwater management” (361 documents), “water policy” (335 documents), and other water-related dimensions, such as “drainage”, “water security” and “wastewater management” (with 152, 110, and 40 documents, respectively).

Note that important key emerging water concepts related to the adaptation to climate change were poorly addressed (Table 4) despite being critical dimensions of an efficient adaptation planning process, such as water governance (31 documents), stakeholders’ participation (10 documents), stakeholders’ engagement (08 documents), and integrated water management (06 documents).

Table 4. Poorly articulated concepts in the literature search.

Concepts	Number of Documents
Management practices	51
Water governance	31
Stakeholders’ participation	10
Stakeholders’ engagement	08
Integrated water management	06

This lack continues to cast doubt on how the water sector is to adapt to climate change, not only in terms of physical adaptation (modern technology and long-lived infrastructure), but also in terms of institutional adaptation, which includes the social dimension and the water communities [35,36]. In the water sector, site-specific solutions need to be considered within the broader context of integrated water management approaches. A lack of regard for particular contexts, alongside poor planning and overemphasis on short-term outcomes, or failure to account for possible climatic consequences and adaptation limits, can result in maladaptation or “an adaptation that does not succeed in reducing vulnerability but increases it instead” [3].

The scales of water systems at which the adaptation is applied varies from ecological scales, being the most mentioned (including rivers with 1526 documents, watersheds with 360 documents, and stream flows with 80 documents, etc.), followed by the water distribution systems (including water supply systems with 326 documents and water infrastructure systems with 292 documents), and others. However, despite the multiplicity of scales that are relevant to the adaptive pathways to climate change, the irrigation systems are receiving less attention (only 72 documents), notwithstanding the large share of water consumed by the agricultural sector. This might be related to the fact that adaptation is a newly highlighted challenge in irrigation systems as compared to other scales. Yet, this does not exclude that the current formal processes and institutional organizations are ill-equipped to deal with building adaptive irrigation systems. Nevertheless, this fact highlights the compelling need to address these critical research questions, and once again underlines the importance of considering the institutional and organizational arrangements in the adaptation processes.

3.4.2. Water-Related Adaptive Approaches

The search revealed two pathways of water-related adaptive approaches: (1) static adaptiveness and (2) dynamic adaptiveness. Static adaptiveness aims to concentrate all efforts on protecting the basic existing plan from failure via proactive interventions and actions. It has been used in several design approaches, such as (i) Assumption Based Planning (ABP), (ii) Adaptive Policy Making (APM), and (iii) Robust Decision Making (RDM). With ABP, the challenges are to identify important assumptions and to select the vulnerable ones within the planning time horizon to define signposts that indicate the drawbacks of an assumption, and to enable hedging actions that preserve important options in light of the plausibility of that assumption’s failing at some point [37]. The APM suggests the formulation and implementation of new policies that combine time-urgent actions with other actions that maintain necessary flexibility in the future. With an explicit provision for learning, this adaptive approach implies fundamental changes in policy-making by creating policies that respond to changes over time [38]. RDM is a quantitative decision-analytic approach based on the predict-then-act framework. The approach rests on a full understanding of the ranges of deep future uncertainty, suggests a set of robust strategies, and incorporates a vulnerability-and-response-option framework as part of a management strategy [39].

On the other hand, dynamic adaptiveness aims to alternatively develop parallel actions to be addressed when required. This approach includes the Multi-Objective Robust Decision Making (MORDM) [40], the Engineering Options Analysis (EAO) [41], and the Dynamic Adaptive Policy Pathways (DAPP) [32].

The current study highlights the main limitations of the above literature on water-related adaptive approaches. First, the RDM, being very generic, addresses all the future uncertainties together, including climate change, using the same scenario analysis rather than classifying the uncertainties and tackling each of them with the appropriate analysis tool. The RDM assumes that the current changing conditions are to be extended over the entire planning horizon, rather than characterizing and understanding the future climate and hydrological uncertainties. Moreover, static adaptiveness, being so limited, considers only short-term options instead of combining short-term options and long-term actions,

and considering the upcoming changing circumstances. Besides, the MORDM considers robustness as a key criterion for evaluating alternative decisions under conditions of deep uncertainty, without considering the flexibility, reliability, and vulnerability options. Finally, the DAPP approach relies only on policy rather than combining it with the engineering aspect.

Although there remains a persistent lack of specificity around the boundaries and the limitations of these approaches, a limited number of authors have tackled these gaps. Haasnoot (2013) suggested that a new paradigm for planning under uncertainty should be developed by combining short and long-term options, following a dynamic adaptation over time to meet changing circumstances [32]. Maier (2016) proposed a multidisciplinary approach to dealing with the uncertain future that includes: (i) simulating uncertainties according to different sets of hypotheses by representing future coherent pathways; (ii) understanding the levels of insensitivity to changes in future conditions in terms of water system performance; (iii) developing adaptive strategies alongside with the commonly used static counterparts [42]. Haasnoot (2018) developed a design framework using a monitoring plan as part of the Dynamic Adaptive Policy Pathways to support water-related infrastructure investments under uncertain climate change. The approach suggests criteria to evaluate the monitoring signposts as measurability, timeliness, reliability, and institutional connectivity [43].

3.5. Co-authorship Country Analysis

The co-authorship country analysis revealed 118 countries, but only 74 met the minimum requirement of five publications related to the topic of adaptation in water systems to climate change. This analysis (Figure 5) shows that most documents originate from the USA (37% contribution), followed by the People's Republic of China (15% contribution), England (9%), and Australia (9%). On the other hand, Germany and the Netherlands, with a relatively low number of publications, yielded a high number of citations, which hints at the excellent quality of the publications (Table 5).

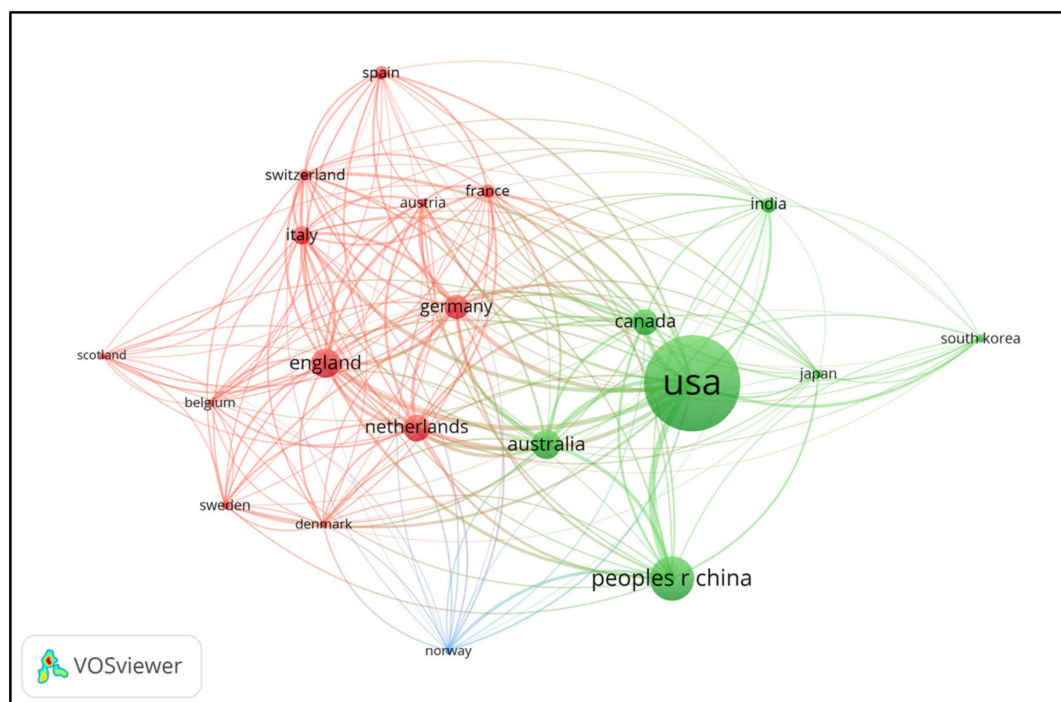


Figure 5. Network map of top 20 countries by co-authorship based on the total link strength.

Table 5. Top 5 countries ranked according to their total link strength.

Country	Documents	Citations	Total Link Strength
USA	1334	42,237	983
England	341	14,900	550
Germany	268	12,316	502
Netherlands	307	12,643	494
China	541	10,351	465

The top 20 ranked countries include the traditionally defined developed countries in Europe (Switzerland, Italy, France, and Spain) and North America (Canada). This might be mainly related to the fact that these countries house a large number of highly-rated research centers and universities.

Although there were still no developing countries ranked in the top 20 countries, the topic of water systems adaptability to climatic change is receiving more attention in Africa (Tunisia and South Africa), South America (Columbia, Peru, and Chile), South Asia (Nepal), and Western Asia (Turkey, Jordan, and Lebanon). Al-Omari et al. (2014) proposed an adaptation approach to climate change in Jordan: the Case of the Red Dead Canal (RDC) project [44]. Almazroui et al. (2018) developed a new approach to the design of water infrastructure based on a hydro-meteorological model [45]. Amamou et al. (2018) studied adaptation strategies as perceived by Tunisian farmers to cope with attributable climate change variability [46]. However, these countries still lack the experience that the developed countries have gained over their long history with climate change issues: a traditionally earned experience illustrated through their management strategies, new policies, and adaptive technologies.

4. Conclusions and Recommendations

The analysis of water systems' adaptation to climate change uncertainties would ideally require a deep evidence-based assessment across all the dimensions (i.e., water, climate, governance, policy, and decision making), as well as agreements on how significantly these dimensions are tackled, related, and defined.

Given the multiple dimensions of this work, it is important to note that the data used in this framework were obtained from a broad range of studies, developed using different methods and tackling the topic from different perspectives. This broad analysis may increase the uncertainty level of the results. However, at some point, it is difficult to establish commonality across all the studies covering a particular topic.

Data collection was limited to the core collection of WoS and refinements that were applied, such as "document categories", "documents types", and "languages", while other international databases (e.g., PubMed or Scopus) may have been combined. However, it was decided to use the WoS database since it is perceived to be more accurate and reproducible, as well as being the world's most trusted citation index for research and being used as the standard by official organizations.

The study considered "climate change" as the sole main driver of uncertainty that defines the adaptation strategies and measures that are largely contextual. This may lead to underestimating the other drivers, such as population growth, increased demand, and migration, etc., and might have missed some papers that do not specifically use the search terms that were used, while still referring to similar framings and subjects, e.g., flexibility, adjustment, or conversion of water systems to climate change. Nonetheless, this research investigated the bulk of the global scientific production of academic literature from 1990 to 2019. The combined use of statistical methods and bibliometrics resulted in quantitative statements that captured the interdisciplinarity of research topics, crossing the boundary of specific disciplines, and has provided a valuable and seminal reference for researchers and practitioners in the adaptation of water to climate change research.

The trend analysis showed exponential growth in the research interest concerning the subject of adaptation in water systems to climate change uncertainties during the study period. The research showed that different disciplines were concerned with the subject, while the majority of research was mainly derived from the Environmental and Water Management fields. This search shows, through different analyses (co-authorship, journals citation, and country analyses), that the scientific literature is significantly interested in the approach to adaptation in water systems to climate change uncertainties, where there are countries, such as the USA and the UK, that have contributed to the largest number of national and international collaborative documents.

The analysis shows that a large proportion of the literature concerning the adaptation of water systems to climate change tends to focus primarily on water resources planning and management (implied by investors, water managers, and the government), and also on building adaptive water supply infrastructure (implied by designers, and engineers). This infrastructure-centered management can be highly problematic, as there remains a relatively fractured understanding of the governance principles and the engagement of stakeholder's options in implementing an efficient adaptation planning process.

This search also addresses the main limitations of adaptive water approaches confronted in the literature, and suggests the following opportunities. Adaptive approaches should be built on a good understanding of the future climate and hydrological uncertainties. To this aim, uncertainties should be classified, mapped, and modelled with the appropriate analysis tool. An effective adaptive approach should be built on a set of combinations involving short-term options and long-term actions, policies, and engineering processes, and should equally consider robustness, flexibility, reliability, and vulnerability options within the planning process.

It is strongly recommended to address the short-term concepts, such as “resilience”, which includes reconsidering the communities' resilience to drought, developing climate-resilient infrastructures, and also evolving some new strategies that guarantee an efficient and equitable service to the water users under limitations.

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