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Assessing the Inclusion of Water Circularity Principles in Environment-Related City Concepts Using a Bibliometric Analysis

Ana Catarina Miranda [1,*], Teresa Fidélis [2], Peter Roebeling [3,4] and Inês Meireles [5]

[1] Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
[2] GOVCOPP, Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal; teresafidelis@ua.pt
[3] CESAM, Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal; peter.roebeling@ua.pt
[4] Wageningen Economic Research, Wageningen University and Research, 4, 6708 PB Wageningen, The Netherlands
[5] RISCO, Department of Civil Engineering, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal; imeireles@ua.pt
* Correspondence: anacatarinamiranda@ua.pt; Tel.: +351-911-883-278

Abstract: Cities face increasing water pressure and supply issues, jeopardizing the balance between growth and sustainable water resource use. Green, resilient, smart, circular, blue, water sensitive, or water-wise city concepts are increasingly part of the design of strategies to rethink cities. These concepts have motivated many studies, but little is known about their relative relevance among the scientific community and how they consider water circularity. The objective of this study is to assess how these city concepts incorporate water circularity principles. The assessment is based on a bibliometric analysis of scientific articles recently published. The findings show that despite the wide number of articles dedicated to the various city concepts, water circularity-related challenges are still a small niche of concern, strongly driven by European authors. Moreover, our study showed that water circularity principles are not equally considered among the different city concepts. This uneven assimilation of principles in influential city concepts unveiled gaps regarding water circularity. This brings a new perspective to the use of more integrated definitions, highlighting the importance of such principles in the future use of these concepts when envisioning roadmaps toward sustainable water use in cities.

Keywords: city concept; circular economy; water; bibliometric analysis

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1. Introduction

Water is one of the most endangered natural resources on the planet, and its scarcity is the locus of environmental challenges faced by cities, which rush to find innovative solutions to decrease water demand and manage its availability [1–3]. Cities are the hub of large agglomerations with significant water consumption patterns (human consumption, production activities, cleaning of urban spaces, among others) that challenge water infrastructures, practices, and intensities of their use, increasing the complexity of urban water systems and threatening the path to sustainability [4]. As the center of numerous water-related environmental challenges such as floods, droughts, and quality issues aggravated by overconsumption, cities are making considerable efforts to mitigate water scarcity and improve urban resilience with innovative solutions that require technology, governance, knowledge capacity, and reliable roadmaps [5]. However, the integration of water sustainability criteria into investment decisions remains a blind spot, evident by the unclear formulation of water policies [6].

The unsustainable use of water resources in the past, combined with increasing pressures to achieve sustainable goals, accrues the importance of breaking outdated linear economic models and transitioning to a Circular Economy (CE) [7–9]. Water is one of the most important resources for production [10] and the most shared resource across the entire supply chain [7]. Applying water circular principles can potentially address several challenges of urban resource management by diversifying water sources and alleviating pressures while mitigating water scarcity [11,12]. Water use has been modeled using linear models in a "take-use-discharge" design approach, which has had adverse impacts on the natural water cycle [13]. The related economic and environmental losses, as well as additional expenses to accommodate excessive human consumption patterns have pushed CE to the forefront of political agendas [14]. However, evidence-based theoretical frameworks to guide implementation are still lacking, according to Velenturf and Purnell [15].

A CE with sustainable water usage at its foundation manages water, materials, and energy in closed loops in order to balance the natural and human water cycles [13]. This calls for a paradigm shift towards an "avoid-reduce-reuse-recycle-replenish" logic that prioritizes environmental flow and makes human interactions with natural water systems less disruptive [13]. Additionally, recent studies show a growing need to better incorporate water-related concerns into scientific definitions of CE [16].

The circularity of water has been considered a key facilitator to increasing sustainability in cities by preventing contamination, reducing pressures on the environment, enhancing supply, and increasing competitiveness [17]. Among others, the application of closed loops, the maximization of the water life cycle, the search for alternative sources, and the implementation of cross-sectoral circular practices are among the top priorities of water agendas in cities [1,4,18].

Numerous international organizations have been boosting the development of cities better prepared for the future [18–21]. This development entails research, innovation, and commitments to develop new high-tech applications, climate change adaptation, sustainable use of resources, and a reformulation and re-adaptation of the urban water cycle to increase reliance on urban water systems. To respond to various challenges of sustainability, many city concepts have emerged, aiming to put into practice concepts such as resilience, information technology innovation, CE, green and blue infrastructures, nature-based solutions, and water.

Among the various existing city concepts, a few examples include the following:

- Sustainable cities, working towards equity in access to basic services (e.g., water), more inclusive and sustainable urbanization, and the building of participatory capacity, as referred to in the 11th sustainable development goal (SDG) set by the United Nations: "make cities and human settlements inclusive, safe, resilient and sustainable" [22];
- Resilient cities, anchoring its principles in reducing vulnerability and exposure to extreme events such as floods and droughts, increasing resistance, absorption and recovery capacity, and emergency preparedness [23,24]. The concept of resilience and climate change appears as a set of policy solutions, especially in urban contexts, to cope with increasing natural hazards. These go from preventing, absorbing, and recovering from shocks while maintaining their essential functions, structures, and identity;
- Smart cities, based on increasing and improving the digitalization of city information, are often designed through collaborative and multi-stakeholder processes. These cities have been considered a relevant aid to foster more sustainable and resilient practices and deliver more efficient and inclusive urban systems [20,25,26];
- Green cities focus on better use of ecosystem services, nature-based solutions, and green and blue infrastructures in urban environments to improve the quality and resilience of environmental assets (e.g., air, water, land, soil, or biodiversity) [21,27–31];
- Circular cities aim at the elimination of the concept of waste, keep assets at their highest value with the support of digital technologies, and decouple economic growth from the consumption of finite resources while increasing the resilience of cities [18,32–34].

The adoption of circular principles in cities has become part of many urban agendas to enhance governance and social innovation [35–37].

As previously highlighted, the growing concerns over the need to preserve water have placed integrated water resources management as a critical target for achieving sustainability. Blue cities [27], water-sensitive cities [38], and water-wise cities [19] are the following three examples of water-centric city concepts:

- Blue cities focus on the water, playing a prominent role in urban development and planning. Under this concept, blue infrastructures (e.g., natural or artificial water bodies, often associated with green infrastructures or other nature-based solutions) have important functions of temperature stabilization, CO_2 absorption, and mitigation of urban heat island effects [27];
- Water-sensitive cities focus on water-sensitive urban design to ensure environmental repair and protection, supply security, public health, economic sustainability, enlightened social and institutional capital, and diverse and sustainable technology choices [39];
- Similarly, water-wise cities focus on developing strategies and solutions toward more sustainable urban water management by mobilizing leadership culture, governance arrangements, professional capacity, and innovative technology. All water within the city is managed holistically, recognizing the connection between services, urban design, and the resilience to unexpected social, economic, or bio-physical shocks while replenishing the environment [19].

Figure 1 summarizes the interconnectedness of the referred city concepts regarding water-related challenges.

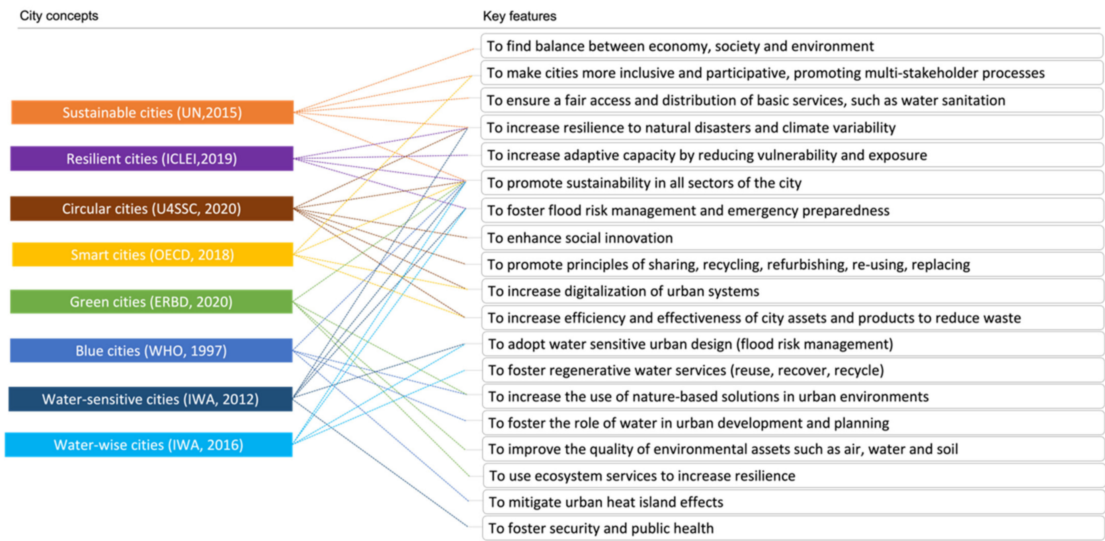


Figure 1. Key features and principles of city concepts and their interconnection.

It is often challenging for practitioners to make sense of the numerous terms and concepts that arise in the literature. The relations between the abovementioned city concepts, although “logical” since they address similar environmental subjects, are not always fully understandable regarding the limits of their approaches. While scientists, organizations, and governments have increased the use of these city concepts, little is known about how water circularity is being considered in the various city concepts and associated definitions. Several authors have been studying the literature on various city concepts likely to influence practice [40–45]; however, studies covering the variety of environment-related city concepts, as considered in this article, are still lacking, let alone the consideration of water circularity concerns.

This article assesses how these environment-related city concepts incorporate water circularity principles. To this end, a combined bibliometric and focused content analysis of the scientific literature over the period 2000–2020 was performed regarding a set of city concepts. Considering scientific literature as a major driver of development and dissemination of knowledge and the potential to influence practice, this article analyses how water circularity is considered in a wide set of city concepts and related definitions.

2. Materials and Methods

The study of the scientific literature about a set of city concepts and how they consider water circularity used a combined bibliometric and content analysis approach. The city concepts selected for this study emerged out of a preliminary search of scientific articles crossing the keywords "city" and "water" and including sustainable city, smart city, green city, resilient city, circular city and also water-related city concepts, which include blue city, water-sensitive city, and water-wise city. Bearing in mind the research objectives, the research methodology was divided into three main phases, namely creating a database, bibliometric analysis, and analyzing a set of selected definitions for each city concept (Table 1).

Table 1. Objectives and analytical steps.

Research Components	1st Phase	2nd Phase		3rd Phase
Objectives	To display how these city concepts have emerged in literature through time.	To highlight major characteristics of the scientific community working on these city concepts and how water and circularity appear represented in this context.		To assess the inclusion of water circularity principles on these city concepts
Approaches used	Creation of a database of articles divided in different groups according to each city concept	Crossing the articles of phase 1 with "water" and "circular economy". Aggregation of the articles on blue city, water-sensitive city, and water-wise city into a designated water-related city concept.		Selection of definitions out of the 10 most cited articles from each group of articles found in phase 2. Analysis of definitions that include water circularity principles.
	Sustainable city	+water	Co-authorship by country Co-authorship by author Citation between authors Co-occurrence of keywords.	
		+circular economy		
	Smart city	+water		
		+circular economy		
	Green city	+water		
		+circular economy		
	Resilient city	+water		
		+circular economy		
	Circular city	+water		
	Blue city	+water		
		+circular economy		
	Water sensitive city	+circular economy		
	Water wise city	+circular economy		

The first phase gives an overall picture of the relative attention given by the scientific community to the different city concepts. It was undertaken by analyzing the number of articles published and their evolution in the last two decades. For this purpose, a series of searches using the Scopus platform was made for each city concept referred to above. The city concepts were used as keywords associated with the title, abstract, or keywords of the articles and reviews written in English and published in scientific journals between 2000 and 2020. This search generated a database of articles associated with the eight city concepts presented in the next section.

The second phase further explores major features of the articles that cross each city concept with water and CE to assess their distribution and focus. To avoid redundancy issues, articles on circular city were not cross-cut with the term circular economy, and water sensitive city and water-wise city were not cross-cut with the term water. In this step, the articles about blue city, water-sensitive city, and water-wise city were gathered in a composite concept named water-related city given the limited number of articles found. The analysis used the following bibliometric features:

i. Co-authorship relations by country to study the distribution of the authors;
ii. Citation relations between authors, including the number of citations and their relation, to study potential influencing authors;
iii. Co-occurrence of authors' keywords to study the focus through the dominant keywords.

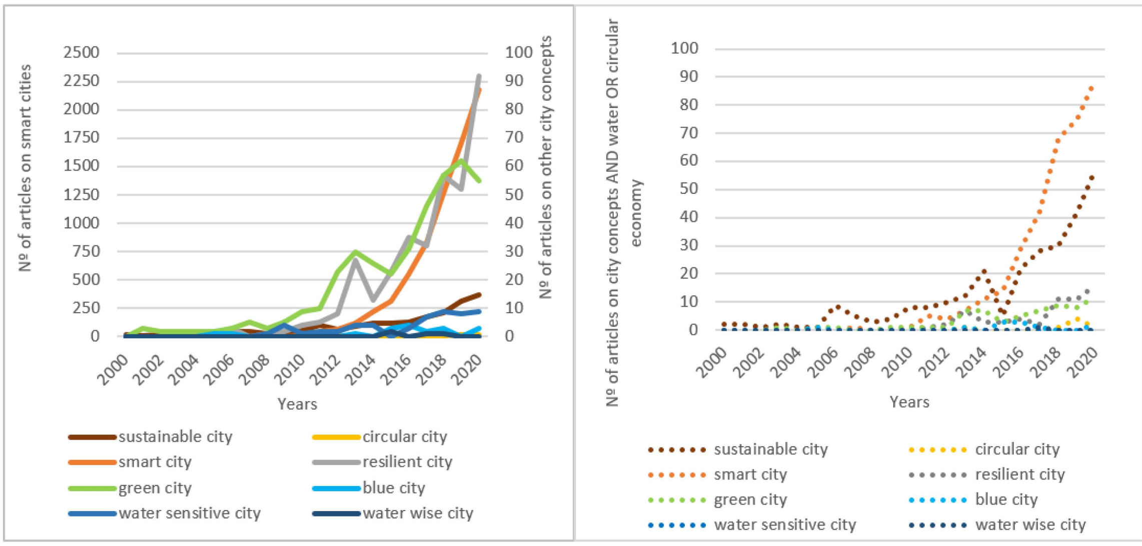
The analysis is performed using the "VOSviewer" software (www.vosviewer.com, accessed on the 14 December 2021) to map the selected literature. This software allows a visual representation of bibliographic databases to explore major features of the authors' communities and publications [46]. The VOSviewer software uses as input the excel files retrieved from Scopus to generate figures based on the visualization of similarities technique [46]. These distance-based network figures are composed of nodes, clusters, and direct lines linking these elements—with distance and disposition reflecting how strong the relationship between those elements is. Using this tool to characterize an extensive database through the presentation of clusters facilitates reading and visualization of highly influential documents, schools of thought, and patterns of particular interest, often used in various interdisciplinary studies [47–49].

The third phase analyses a set of selected definitions associated with each city concept, their main approaches to water, and the way they consider water CE principles. For this purpose, and due to a large number of articles, only the top ten cited articles for each city concept were used. When the number of articles about a particular city concept was less than ten, all articles were considered. The selection of definitions focused on the details under which water and the principles of water circularity were referred. Among the different definitions identified, only the two most complete were selected for further analysis, i.e., the definitions that better reflect the role of water circularity in the city concept. The principles of CE applied to water used for the analysis are supported by the work of EMF and Arup [11], and include the following measures: (i) avoid use, rethink products and services, and eliminate ineffective actions; (ii) reduce use, improve water use efficiency, and perform better resource allocation and management; (iii) reuse water within an operation (closed-loop) and for external applications; (iv) recycle within internal operations or external applications; (v) replenish by returning water to the river basin. The selected definitions are summarized in table format, and the analysis of principles is systematized in matrix table format.

3. Results

3.1. Evolution of Articles

The articles associated with each city concept were used to portray the evolution of publications, and, with that, the relative attention given by the scientific community. The searches for the city concepts used for analysis generated a total of 10,205 scientific articles over the 20-year period considered. The evolution of the articles is presented in Figure 2. On the left side are the general numbers related to each city concept, and on the right side, the number of articles crossing each city concept with the terms water and circular economy.



(**a**) (**b**)

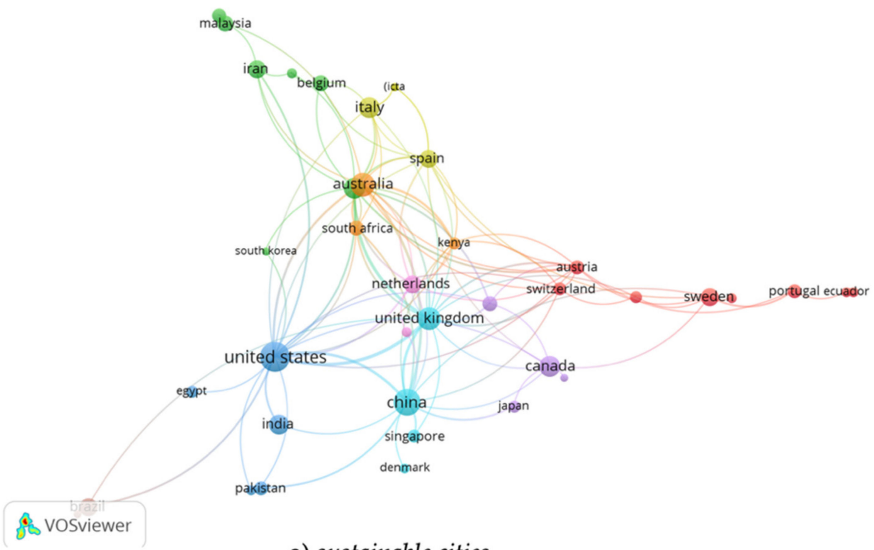
Figure 2. Number of articles, per year, addressing the thematic of city concepts (**a**); city concepts AND water OR circular economy (**b**). Left graphic: Sustainable cities and smart cities (left vertical axis); circular cities, resilient cities.

Both graphics show a slow increase in the number of articles for all city concepts until 2010, after which growth trends become visible. However, when crossing city concepts with water and CE, different findings are noticeable. First, they show that the number of articles crossing each city concept with water or CE is much smaller. Second, they show that the articles on smart cities, resilient cities, and green cities have a significant increase after 2010–2012, while for the other city concepts, the evolution is less prominent. A closer look at the graphic on the right side also shows that the articles crossing smart cities and sustainable cities with water or CE are boosting. On the contrary, the number of articles related to circular, blue, water-sensitive, and water-wise cities has not increased. The articles on water-related city concepts represent a small niche in the literature on environment-related city concepts.

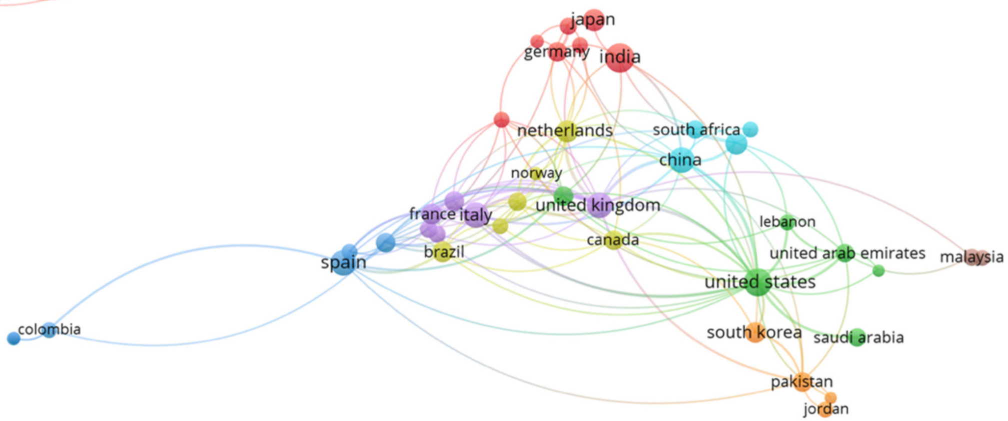
3.2. Bibliometric Features

3.2.1. Co-Authorship Relations by Country

The first bibliometric feature explored the co-authorship by country using their affiliations, as presented in Figure 3a–f. Authors affiliated with institutions on most continents (except Antarctica) are represented, with co-authorship connecting countries all over the world. Among the different city concepts, the United States of America, the United Kingdom, Australia, India, the Netherlands, Italy, and Spain are among the countries with more co-authorship relations. Smart cities and sustainable cities show authorship spread worldwide with the predominance of the United States, the United Kingdom, and China. Moreover, all city concepts show a strong presence of European countries, especially the Netherlands and the United Kingdom. These countries appear to be two front-runners in the research around city concepts. Two examples are the cases of resilient cities (Figure 3d) and circular cities (Figure 3f) where European countries are evident (the United Kingdom and the Netherlands). For water-related city concepts (Figure 3e), the two countries most evidenced are the Netherlands and Australia. The Netherlands shows much more co-authorship with other countries and a superior level of collaboration between authors affiliated with European institutions.



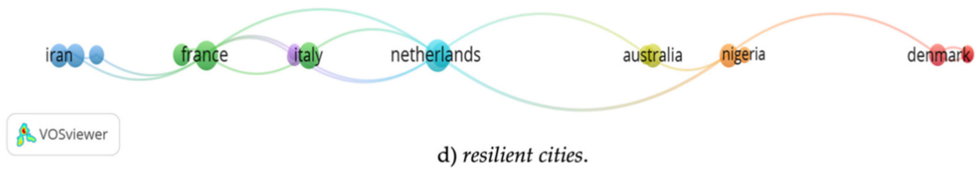
a) *sustainable cities*.



b) *smart cities*.

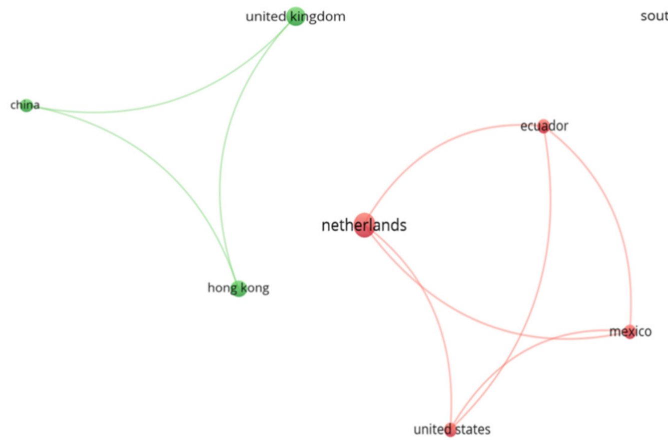
c) *green cities*.

Figure 3. *Cont*.



d) *resilient cities.*

e) *water-related* cities.



f) *circular cities.*

Figure 3. (**a**–**c**) Relation of articles co-authorships between countries: (**a**) articles about sustainable cities; (**b**) articles about smart cities and (**c**) articles about green cities. The dimension of each sphere varies according to the number of articles with authorship from that country. All labels indicate at least one document per country and at least 5 citations of a country. The thickness of the links varies according to the number of shared authorships between two connected countries. Software: VOSviewer. (**d**–**f**) Relation of articles co-authorships between countries: (**d**) articles about resilient cities; (**e**) articles about water-related city concepts and (**f**) articles about circular cities. The dimension of each sphere varies according to the number of articles with authorship from that country. All labels indicate at least one document per country and at least five citations of a country. The thickness of the links varies according to the number of shared authorships between two connected countries. Software: VOSviewer.

3.2.2. Citation Relations

The number of citations and their relations among the authors provides insights about potential influencing authors in the overall discourse and interconnectedness of research. Figure 4a–f present the citation relation between authors with at least five citations. Overall, it is visible that a small number of clusters of authors and limited interconnectedness. Most city concepts show a very small number of citation relationships between authors, constituting small communities with poor aggregation. Certain city concepts show clusters, where some authors are more centralized in the figure [39,50,51] and linked with other authors, placed more peripherally (Figure 4a,c,e, respectively).

Among the most influential authors working on different city concepts, the following are detached:

- For sustainable cities, Kennedy et al. [50] address urban metabolism associated with growth in metropolitan regions and how certain metabolic processes of water, energy, materials, and resource flows impact the sustainability of cities. This author forms clusters of citations with others exploring the paths of urban metabolism, urban ecosystem services, and urban political ecology in transitioning cities towards grey/green sustainability [52] and authors approaching integrated urban metabolism frameworks through bottom-up ecological footprint analysis in urban environments [53];
- For green cities, the work of Thorne et al. [51] investigates the barriers to the implementation of blue-green infrastructures for urban flood risk management, which are mostly associated with biophysical and socio-political uncertainties;
- For the case of water-related city concepts (Figure 4e), it is visible a more aggregated community of authors sharing citations. Different citation relations are often represented in different colors (green, yellow, and red, for instance), which in this case represents, among others, a subject widely discussed in this small community of authors—the subject of water-sensitive cities.

For water-sensitive cities, Brown et al. [39] propose an urban water transition framework to assist water strategists in building capacity and institutional reforms required for sustainable urban water management in future water-sensitive cities. This author shares citations with many others, namely, approaching the development of strategic programs to assist transitioning water-sensitive cities to provide operational guidance to planners and designers and decision-makers to facilitate sustainability transitions in urban water systems [54]. Other studies on water-sensitive cities are assessing water-sensitive interventions through the quantification of the water performance of urban systems in cities [55], the integration between land-use and water resource sectors in city regions, and how urban metabolism could foster better integration between the two sectors [56]. From a more empirical point of view, Dolman et al. [57] explore the transition of water sensitive cities from the experience of urban water management and water-sensitive urban design in the Netherlands and UK, and Floyd et al. [58] present the case study of Sidney as a city in transition into a water sensitive city, studying the role of participation and responsibility in reducing water-related governance challenges in water sensitive cities.

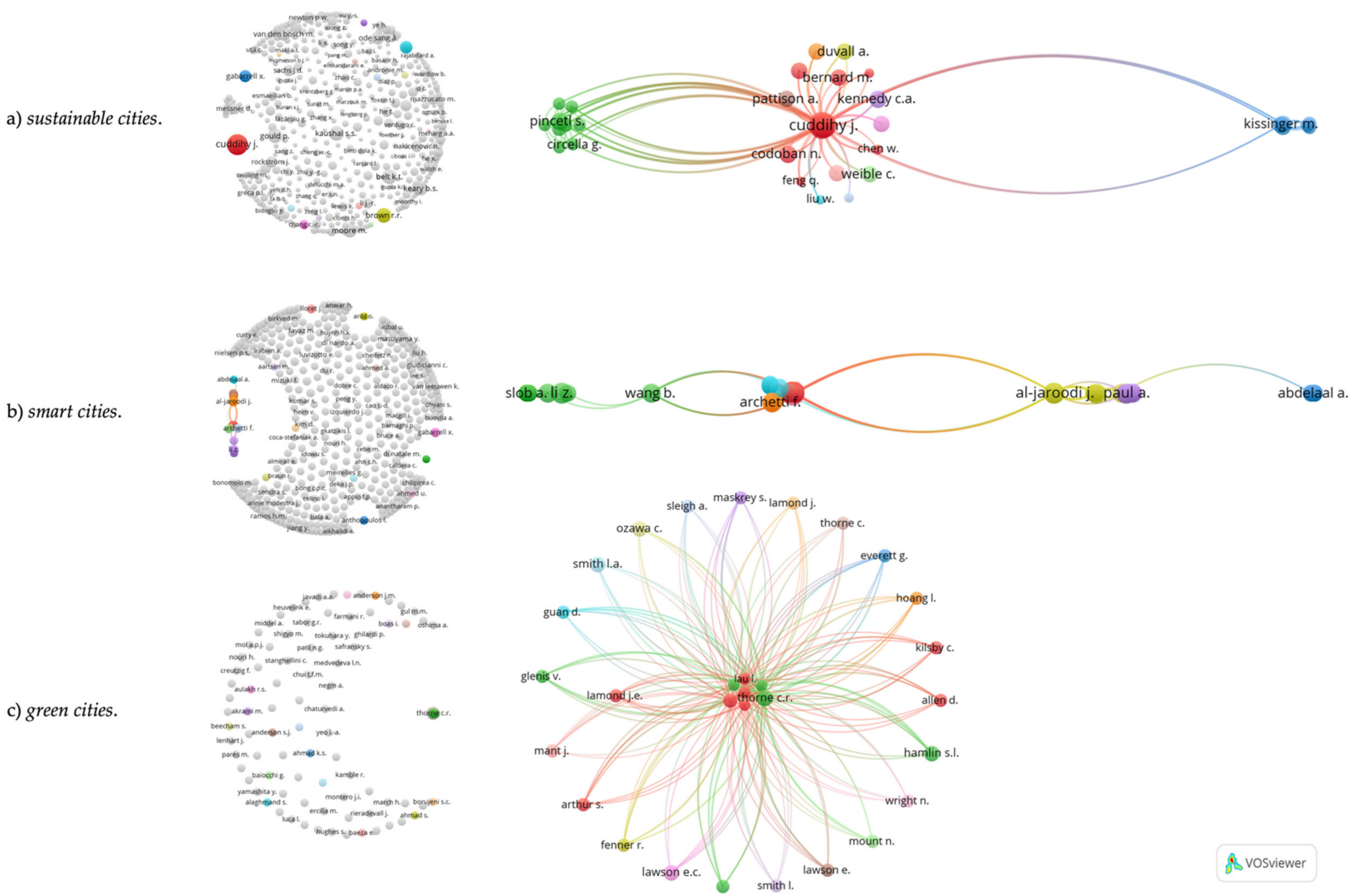
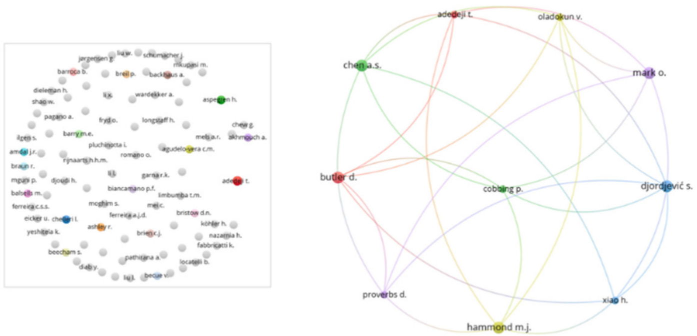
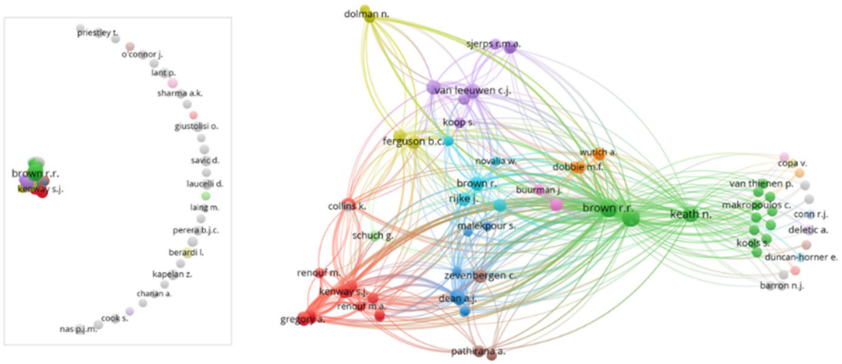


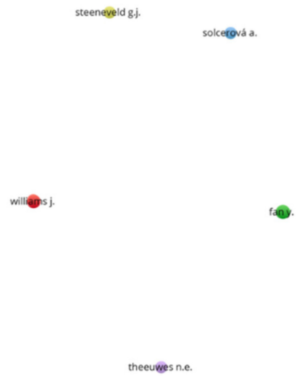
Figure 4. *Cont*.



d) *resilient cities.*



e) *water-related* cities.



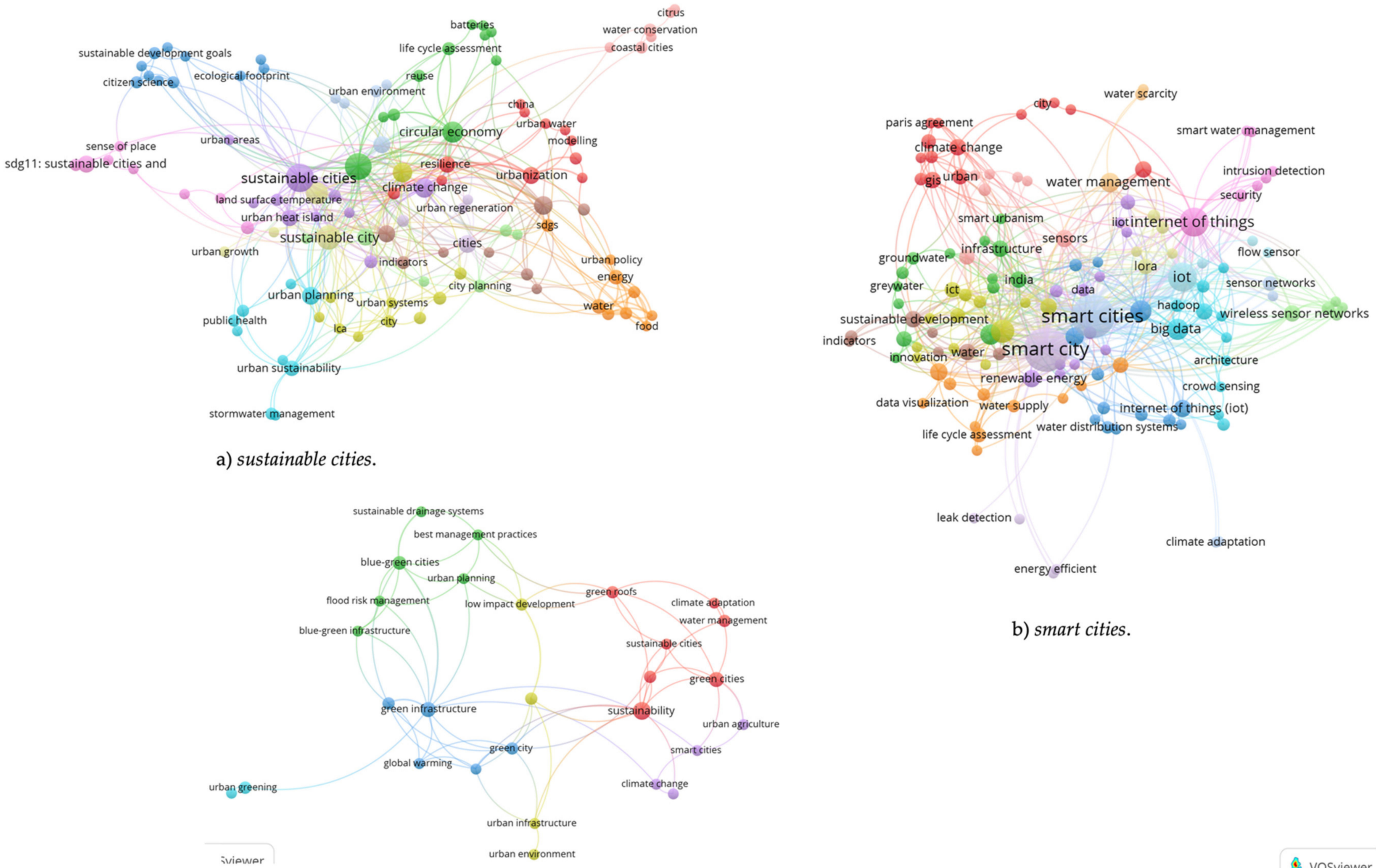
f) *circular cities.*

Figure 4. (**a**–**c**) Citation relations between main authors involved in publications around city concepts: (**a**) articles about sustainable cities; (**b**) articles about smart cities and (**c**) articles about green cities. The dimension of each sphere varies according to the number of citations for each author. All spheres indicate at least one document per author, with at least five citations. The thickness of the links represents the frequency of citations between those two authors. Software: VOSviewer. (**d**–**f**) Citation relations between main authors involved in publications around city concepts: (**d**) articles about resilient cities; (**e**) articles about water-related city concepts and (**f**) articles about circular cities. The dimension of each sphere varies according to the number of citations for each author. All spheres indicate at least one document per author, with at least five citations. The thickness of the links represents the frequency of citations between those two authors. Software: VOSviewer.

3.2.3. Co-Occurrence of Authors' Keywords

The analysis of the 'co-occurrence of authors 'keywords" reflects major subjects discussed within a specific city concept. The authors 'keywords and respective connections are presented in Figure 5a–f. The analysis of the figure outlines the following features:

- All of the city concepts studied include "sustainability" or "sustainable development" as keywords.
- Smart cities are often associated with keywords such as "internet of things" and "climate change" (Figure 5b); green cities with green infrastructures, roofs, blue-green cities, and infrastructures (Figure 5c). Water-related keywords also appear associated with smart cities ("water scarcity", "groundwater" and "greywater") and with green cities ("flood risk management").
- Resilient cities (Figure 5d) use "resilience" as the keyword with the most occurrences and connections, occupying a central place in the figure and showing a close relationship with "climate change". It is also noteworthy that it has a relation with urban and water-related terms (mostly flood-related terms). Curiously, "water sensitive urban design" occurs with "resilient cities", evincing a close relation between resilience and water.
- Articles on water-related cities (Figure 5e) refer to "water-sensitive cities" as a primary keyword, suggesting a more deficient use of terms such as "blue cities" and "water-wise cities" in literature. Other keywords such as "climate change", "resilience" and "water governance" are also frequently used.
- For circular cities (Figure 5f), the dominant keywords form three clusters. The first one where the "circular economy" is a keyword associated with cities, resources, infrastructure, policy, and the environment. The second one is centered on "urban heat island" and other pollution-related terms, and the third cluster on "climate change adaptation" and "hydrosocial territories".
- The keyword circular economy is only considered in sustainable cities and circular cities, while water-related keywords occur in all sets of city concepts' articles.



a) *sustainable cities*.

b) *smart cities*.

c) *green cities*.

Figure 5. *Cont*.

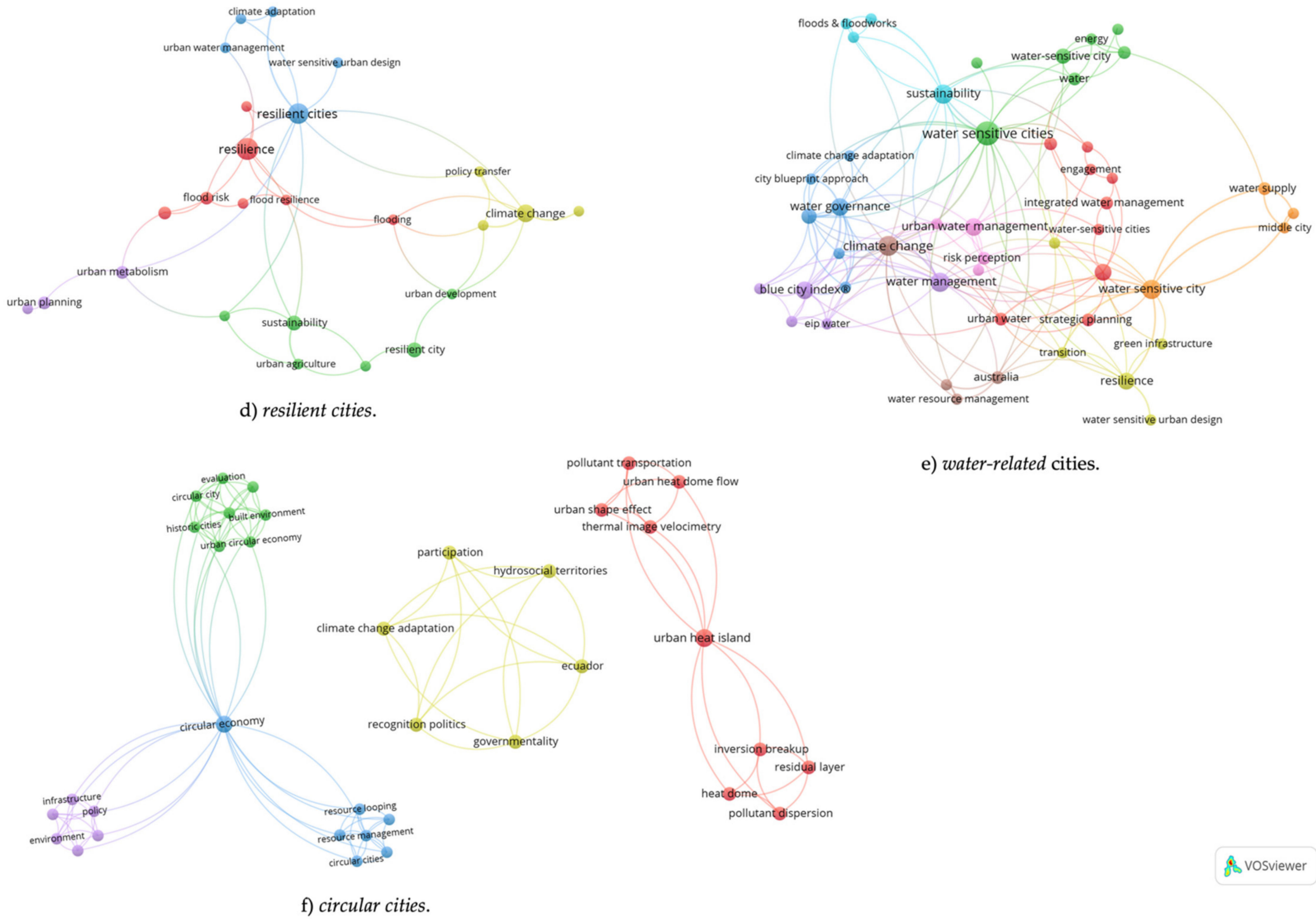


Figure 5. (**a**–**c**) Relation of co-occurrence between authors' keywords: (**a**) articles about sustainable cities; (**b**) articles about smart cities and (**c**) articles about green cities. The dimension of each sphere varies according to the number of times a keyword appears. All spheres indicate that a certain keyword occurred at least twice. The thickness of the links represents the number of times that two keywords occur together. Software: VOSviewer. (**d**–**f**) Relation of co-occurrence between authors' keywords: (**d**) articles about resilient cities; (**e**) articles about water-related city concepts and (**f**) articles about circular cities. The dimension of each sphere varies according to the number of times a keyword appears. All spheres indicate that a certain keyword occurred at least twice. The thickness of the links represents the number of times that two keywords occur together. Software: VOSviewer.

3.3. City Concepts, Water, and CE—Definitions

The key definitions, including references to water circularity principles, were then selected from the ten most cited articles about each city concept and analyzed. They are summarized in Table 2.

Table 2. Water circularity principles in selected definitions of the city concepts.

City Concept	Definitions
Sustainable city (SC)	*(1) one that "(. . .) requires strategies that promote: green buildings;* ***integrated water systems****; cycling, pedestrian, and transit friendly design; urban forestry; local energy production; and neighbourhood waste management." ([50] in [59], 1).*
	(2) where a "trans-disciplinary approach to design with active community engagement and participation is an essential process in contextualising global principles of sustainability in urban design to accommodate local opportunities and constraints from both a physical and socio-economic perspectives. A ***water sensitive city*** *is a fundamental building block towards a sustainable city." ([60], 8)*
Smart city (SM)	*(1) one "that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails, subways, airports, seaports, communications,* ***water****, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens" ([61] in [62], 3)*
	(2) one that "utilizes ICT (Information and Communication Technologies) in a way that could help citizens in daily life using limited resources. (. . .) The key concept of the smart city is to obtain the right information at the right place and on the right device to make a city-related decision with ease and to aid citizens more quickly. (. . .) Weather and ***water information*** *also increases the efficiency of the smart city by providing weather-related data such as temperature,* ***rain****,* ***humidity****, pressure, wind speed and* ***water levels at rivers****,* ***lakes****,* ***dams****,* ***and other reservoirs****. All of this information is collected by placing the sensors in* ***water reservoirs*** *and other open places." ([26], 65–66)*
Green city (GC)	*(1) one that is "designed to restore the environmental and ecological damage. Green cities utilize low impact development (LID) and analogous initiatives to mimic pre-development* ***hydrologic and ecological characteristics****. (. . .) In response to the need to address* ***urban water reuse****,* ***water quality****,* ***and stormwater*** *issues while considering not only* ***water quality deterioration*** *but also* ***inland flooding and water depletion****, LID can be used to develop a city with environmentally sustainable* ***stormwater management****." ([29], 1)*
	(2) one that integrates "green infrastructure (. . .) (as an approach to wet weather management that uses soils and vegetation to utilise, enhance and/or mimic the ***natural hydrological cycle processes of infiltration****,* ***evapotranspiration and*** *reuse' (US EPA, 2008)), which embraces the Blue-Green ideals of reconfiguring the* ***urban water cycle*** *to more closely resemble the* ***natural water cycle*** *and using urban green spaces to help manage* ***stormwater****." (US EPA, 2008 in [51], 3)*
Circular city (CC)	*(1) one that foresees the implementation of looping actions, such as reuse, recycling, and energy recovery in resource flows. "Looping actions could help to address water and energy scarcity in cities, for example through the* ***reuse of grey-water*** *(Andersson et al. (2016); Campisano et al. (2017) (. . .) The implementation of circular, and/or integrated systems (nexus solutions), requires the development of new cultural values and social practices amongst citizens to support them." ([63], 10)*
	(2) one that reuse "wastes, ***water****, energy, products, and in the spatial dimension even entire buildings, sites, and landscapes that lay in a state of abandonment. In fact, the action of "reusing things" and sites implies not only a technical knowledge and capacity, but also a high level of governance and social and technological innovation to identify new value chains and new use values for objects/buildings/sites or parts of them, and to enable their effective reutilization from a technical point of view." ([64], 3)*
Resilient city (RS)	*(1) that "would rely on the management of its ecological footprint (Rees and Wackernagel, 1996), in the sense of using geographically connected lands (Luck et al., 2001) to reduce long distance hazard connexions and greenhouse gas emissions, and by developing the internal recycling of its waste,* ***including water*** *(Grimm et al., 2008a,b; Novotny, 2010)." ([65], 2)*
	(2) one that is anchored on the concept of urban resilience, which "leads to projects and strategies that better integrate ***water and flood risk*** *into city planning and disaster preparedness (Serre 2011). The concept of resilience is presented as one means for urban systems to cope with unexpected shocks and to achieve sustainability over time." ([23], 1)*

Table 2. *Cont.*

City Concept	Definitions
Blue city (BC)	*one that "uses best management practices to understand and* ***govern its water footprint*** *within the bounds of its economic system. Open data and sharing of information are important initiatives to better understand and* ***manage urban water resources*** *to facilitate* ***urban water transitions****." ([30], 2)*
Water-sensitive city (WSC)	*(1) that is "is a conceptual representation of this alternative paradigm for* ***urban water systems, building on sustainable urban water planning*** *and management practices and prioritizing liveability, sustainability and resilience in the design of its institutions and infrastructure. (. . .) cities as* ***water supply catchments****, cities providing ecosystem services and cities comprising* ***water sensitive communities****. (. . .) its innovative aspirations include: (a)* ***harmony between water planning and urban planning****; (b) adaptive and multi-functional infrastructure; and (c) productive and ongoing collaborations between science, policy, practice and community (Brown, Keath, & Wong, 2009; Wong & Brown, 2009)." ([54], 2)*
	(2) that is "the outcome of WSUD (water sensitive urban design) processes, and is considered to be adaptive and resilient to broadscale change (i.e., demographic change, climate change and extreme weather conditions) and ***values water****, promotes conservation and aims to improve liveability (Wong and Brown, 2009). Such a city would achieve this through* ***planning for diverse and flexible water sources*** *(e.g., dams, desalination, water grids and stormwater harvesting), incorporating WSUD for* ***drought and flood mitigation****, environmental protection and* ***low carbon urban water services in the planning system, and enabling social and institutional capacity for sustainable water management*** *(see also Wong and Brown, 2009)." ([66], 2)*
Water-wise city (WWC)	*that applies "resource and energy recovery in their WWT and solid waste treatment, fully* ***integrate water into urban planning****, have multi-functional and adaptive infrastructures and local communities promote sustainable integrated decision making and behavior. Cities are largely* ***water self-sufficient, attractive, innovative and circular by applying multiple (de)centralized solutions****." ([67], 4640)*

As an essential and transversal resource within all urban systems, water is a subject approached from different perspectives in the articles about the city concepts. Some of the definitions were found to be less specific than others, but generally, they all reflect the importance of overcoming water challenges, and some consider the application of principles for water circularity. Integrated water resources management, water-sensitive urban design, and other circular practices are common priorities in conceptualizing most of these city concepts. Governance is also seen as a key factor to the success of cities in transition, namely, through sustainable and innovative socio-cultural practices, active and participatory communities and institutions, and collaborative and integrated decision-making processes. Water is often considered a natural resource that needs to be adequately monitored, as a service that requires improvement, optimization, and higher security of several processes, and also as a vehicle for the implementation of more sustainable practices in cities (as is the case of the use of blue infrastructures and other nature-based solutions). It is visible that the definitions consider water under the following different umbrellas:

- The sustainable city concept refers to water as a part of the sustainable goals and objectives through a systems approach (SC1, SC2);
- The smart city concept approaches water as a target for information production and management (SM2);
- The green city concept approaches water through ecosystem lenses and the associated functions to urban nature and its vulnerability (GC1, GC2);
- The resilient city concept approaches water through the vulnerabilities of urban areas to water risks, especially flooding (RC2);
- The circular city concept considers water as a target of an overall approach to circularity (CC1, CC2).

The analysis of the inclusion of water circularity principles in the definitions of the various city concepts is summarized in Table 3.

Table 3. Matrix table assessing the presence of principles for water circularity in the selected definitions for each city concept. (E–Explicitly considered; I–Implicitly considered).

City Concept Definition/ Principles of Water Circularity	P1—Avoid Use, Rethink Products and Services, and Eliminate Ineffective Actions	P2—Reduce Use, Improve Water Use Efficiency, and Perform Better Resource Allocation and Management	P3—Reuse Water within an Operation (Closed Loop) and for External Applications	P4—Recycle within Internal Operations or External Applications	P5—Replenish by Returning Water to the River Basin
SC1	-	I	-	I	-
SC2	-	-	-	-	-
SM1	I	-	-	-	-
SM2	-	-	-	-	-
GC1	-	I	E	-	I
GC2	I	I	E	-	I
CC1	I	I	E	E	-
CC2	E	I	E	E	-
RC1	-	-	-	E	-
RC2	-	-	-	-	-
BC	-	-	-	-	-
WSC1	I	I	-	-	I
WSC2	I	I	E	E	I
WW1	I	I	I	I	I

The principle P3 (“reuse water within an operation (closed-loop) and for external applications”) is the most considered, followed by P4 (“recycle within internal operations or external applications”). The principles less considered are P1 (“avoid use, rethink products and services, and eliminate ineffective actions”) and P2 (“reduce use, improve water use efficiency, and perform better resource allocation and management”). The principle far from being considered is P5 (“replenish by returning water to the river basin”). The analysis of the table also reveals that the most comprehensive definitions, i.e., those that consider more water circular principles, are those about circular cities (CC1 and CC2), water-sensitive cities (WSC2), and water-wise cities (WWC1).

The analysis of key definitions referring to the principles for water circularity shows different approaches to water and an uneven inclusion of circularity principles. The main results are discussed in the next section.

4. Discussion

Under an overall umbrella of the environment, the approaches to water among the analyzed city concepts, explained by their histories and origin contexts, appear different but complementary. Each concept provides enriched and useful insights for city roadmaps and other policy instruments. This underlines the contributions of Cardoso et al. [5] regarding the importance of water resilience in cities and the contributions of Sánchez Levoso et al. [9] regarding the role of urban systems in the transition towards CE and the development of related roadmaps.

City concepts have been emerging in the scientific discourse and are part of a transition process to face major environmental challenges toward sustainability [22]. As evidenced in the paper, sustainability shapes them as an overall goal, although with different water concern approaches. This is evident by the mentions of water management systems and flood risk prevention [23,26,29,54,63,67], reduction of resource consumption [54,63,67], and improvement of governance structures to build social and institutional capacity [60,63,64], among studies exploring city concepts. Moreover, many of the analyzed definitions also integrate concerns about resilience associated with flood risk management, in line with the work of various authors covering studies of resilience in cities through urban water management [23,29,65]. Curiously, a lack of references to droughts was found in the studied concepts even though this is an environmental challenge that highly motivates water reuse practices among countries worldwide [2,3]. This may be related to the prevalence of the authors' affiliation with northern European countries that struggle more with extreme flood events than with water scarcity [68].

Nevertheless, despite the increasing attention to the various city concepts, as the number of articles shows, and the emerging concerns about water and circular economy, water circularity remains a peripheral topic and is dispersed among very few and small groups of authors. Still, it is evident a niche from European countries is probably associated with the financial support of the EU for research projects and innovation incentives targeted at cities [21]. The results are in line with the study of Winans et al. [33], which reviewed the body of literature on the CE concept and related initiatives and showed that the applications for water cycling remain underemphasized. Contrary to other water concerns such as quality, quantity, or flood management, which are widespread in the various city concepts, circularity concerns are scarcely discussed [69–71]. This is also in line with the work of Williams [63,72], which pointed out that the circularity concept has been explored in literature through the implementation of looping actions within various sectors and industries, for instance (e.g., adaptive reuse of buildings, recycling of material waste, energy recovery from sewage) and less in a holistic conceptualization of a circular approach in a city. After analyzing the literature, Korhonen et al. [14] confirm that CE is an attractive and transformative approach. Much research has been conducted on the subject, with several practical applications but less in deep theoretical and conceptual discussions. The current findings display a recent and still fragmented evolution of the CE concept, essentially focusing on life-cycle approaches, closed loops, product reuse, and waste management [14].

Water-wise cities, covered by a very small niche of articles, reflect a robust approach as they relate water circularity principles with urban planning and active citizenship [54,66,67]. Although these concepts do not have circularity in their names, the circularity is evident in their definitions, which is not the case with the rest of the other city concepts. Considering the lack of references to circularity in the definitions found for smart cities and if being smart implies being smart with water, we can argue that smart cities should learn from the concept of water-wise cities, as argued by Koop and Van Leeuwen [67].

Furthermore, our study deepened the analysis and showed that the water circularity principles, supported by the work of EMF and Arup [17], are not equally considered. Smart and sustainable cities have practically no implicit or explicit references to the principles for water circularity despite the evident boost in publications crossing smart cities and sustainable cities with water or CE. The circularity principles referring to water reuse and recycling are the most considered, particularly in circular, water-sensitive, and water-wise cities. Therefore, these city concepts were found to be the most comprehensive regarding circularity principles. The principles of avoiding and reducing water consumption, improving water use efficiency and management, and replenishment of river basins are less explicitly considered or almost not considered. Although these are well-known principles in water governance literature and practice [1,18,22,36], they fail to be dully taken into account within the most influential city concepts. Even though the emergence of water reuse principles is expected due to the increase in water scarcity, concerns about urban water resources planning call for an approach that considers the longstanding integrated river basin management [1,4,18] but is being shunned to the side.

Water is a resource that cuts across sectors and has multiple dimensions (as a service, a source of energy, and a carrier of nutrients). As such, its role is critical both in the circular economy model and for overall urban management improvement, especially given its interconnection with other challenges such as sustainable mobility, infrastructure management, service digitization, spatial planning, etc. Giving water a proper role in the conceptualization of more sustainable cities could lead to a greater awareness of water challenges in cities as well as a different weight in decision-making processes, mitigating not only the challenges posed to water resources but also other environmental challenges encountered in cities.

This paper gathered a set of city concepts and studied their assimilation of principles for water circularity. The study was based on the city concepts most studied and cited in the literature. These are understood as the ones more likely to influence research, policy-making, and subsequent management practice. By characterizing the bibliometric features around the city concepts, our study undertook a critical analysis of city definitions and unveiled their gaps regarding water circularity, bringing a new perspective for the use of more integrated definitions and highlighting the importance of the principles for water circularity in the future use of these concepts in practice. By doing so, the findings open paths for future research, namely, to assess how these definitions may influence successful transitions through city-to-city learning. Furthermore, water circular economy implementation is inextricably linked with topics such as IWRM, water-sensitive urban design, and water governance. This can both pose challenges and create opportunities for said implementation. More research is needed to understand how governance features accommodate circular practices and what the main technical, financial, and social barriers that stakeholders face when implementing water reuse strategies in different city concepts. The lack of integration of circularity principles in the definitions of these city concepts constitutes a challenge both for researchers (who contribute to the construction of knowledge) and practitioners (who use and apply these concepts). However, the analysis of scientific articles does not provide concrete evidence to understand the use of these definitions outside the scientific community. Also, this study only focused on recent and most cited articles, potentially not including other important and useful definitions from previous years. Further research on less cited articles could enrich this study, for instance, by extending the analysis sample, using other city concepts, or by crossing these subjects with other water-related and circularity-related terms to better explore the role of water and CE in the transition of cities into these city concepts.

5. Conclusions

This article assessed the inclusion of water circularity principles in environment-related city concepts, using a combined bibliometric and content analysis of the scientific literature over the period 2000–2020 regarding particular city concepts and how they consider water circularity. It focused on sustainable, circular, green, resilient, blue, water-wise, water-sensitive, and circular city concepts. Under the umbrella of environmental and historical context-dependent, the city concepts unveil differently but in the overall complementary approaches to water and circularity principles. This complementarity should be taken into due account when envisioning roadmaps toward sustainable water use in cities.

The findings showed that the scientific community associated with water within these city concepts constitutes a small niche, strongly driven by European authors, though spread worldwide, and with very diversified concerns. The study of CE within cities and water is still scantily studied and far from fully covering the principles of water circularity. The study of several city definitions also displayed that the principles of water circularity are only explicitly referred to in circular, water-sensitive. and water-wise cities, though not fully covered. Moreover, while water reuse and recycling practices are acknowledged as important solutions to water-related challenges, other principles are still far from being explicitly considered. This is, for example, the case for replenishing the river basin by returning water to mitigate scarcity.

Despite the different historical, scientific, and methodological contexts underlying the considered city concepts, the analysis undertaken in this study suggests that a deeper understanding of how the city concepts consider water circularity is more valuable than expected.

The different insights obtained by the different definitions provide varied, complementary dimensions of water and circularity that may enrich city development strategies towards sustainability and the design of related roadmaps that advocate the various goals that a city must meet. Cities are struggling to become more circular, resilient, water-sensitive, water-wise, green, blue, smart, and sustainable. The findings also suggest that key and popular city concepts and related objectives and roadmaps need to be further revisited to ensure that core principles for water sustainability are duly attended to. These city concepts are frequently associated with environmental performance goals in cities seeking to cope with urban challenges. Thus, further research is needed to reinforce the findings of this study by approaching roadmaps, strategies, or action plans that inter alia underscore the importance of water preservation in cities and that cope with future uncertainties, where water circularity plays a defining role in the development of innovative solutions.

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