Review

Smart Technologies for Sustainable Water Management: An Urban Analysis

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Abstract: As projections highlight that half of the global population will be living in regions facing severe water scarcity by 2050, sustainable water management policies and practices are more imperative than ever. Following the Sustainable Development Goals for equitable water access and prudent use of natural resources, emerging digital technologies may foster efficient monitoring, control, optimization, and forecasting of freshwater consumption and pollution. Indicatively, the use of sensors, Internet of Things, machine learning, and big data analytics has been catalyzing smart water management. With two-thirds of the global population to be living in urban areas by 2050, this research focuses on the impact of digitization on sustainable urban water management. More specifically, existing scientific literature studies were explored for providing meaningful insights on smart water technologies implemented in urban contexts, emphasizing supply and distribution networks. The review analysis outcomes were classified according to three main pillars identified: (i) level of analysis (i.e., municipal or residential/industrial); (ii) technology used (e.g., sensors, algorithms); and (iii) research scope/focus (e.g., monitoring, optimization), with the use of a systematic approach. Overall, this study is expected to act as a methodological tool and guiding map of the most pertinent state-of-the-art research efforts to integrate digitalization in the field of water stewardship and improve urban sustainability.

Keywords: smart water management; digitalization; urban sustainability

1. Introduction

Freshwater resources have been depleting at an alarming rate due to the growing world population, climate change, and increasing industrialization [1,2]. Notably, researchers predict that 52% of the world's population in 2050 (9.7 billion people forecasted) will be living in water-stressed or scarce regions [3]. In this light, health, environmental, and social concerns necessitate the design and implementation of sustainable water management policies [4–6]. To that end, the United Nations' Sustainable Development Goals (SDGs) have set specific targets for universal and equitable clean water access (SDG#6) [7] and responsible use of natural resources, including freshwater (SDG#12) [8], by 2030. At the same time, projections highlight that 68% of the global population will be living in urban areas by 2050 [9]. Growing urbanization has been accelerating water scarcity in urban areas, leading to severe water imbalance and shortages [10–12]. Therefore, sustainable actions, policies, and technologies towards urban water stewardship, at municipal and/or residential/industrial levels, have been emerging as imperative [13–15].

Following the 4th industrial revolution, urban water management has also been transformed into "smart" [16,17] as the only viable way to achieve water sustainability in the cities of the future [18]. According to the International Water Resources Association [19], "smart water management" utilizes information and communication technology (ICT) and

real-time data to tackle water management challenges by integrating digital solutions into urban, regional, and/or national strategies, indicatively referring to water quality and quantity, efficient irrigation, leakages, pressure and flow, floods, and droughts. On this basis, smart technologies have been considered to improve water resource management and, in turn, limit water scarcity globally [20]. Thus, the European Union has been already funding several research projects in this direction (e.g., [21,22]), while the water market has been shifting to digitalized business models [23]. It should be highlighted that automation in complex urban water systems is principally based on receiving feedback from sensors and then using computer algorithms to analyze signals and propose specific actions [24]. In a broader context, several digital technologies, such as sensors and Internet of Things (IoT) networks, cloud-based technologies, algorithms (e.g., machine learning), as well as big data analytics [25–27] have been used for achieving water security in urban landscapes [15] and industrial facilities [28]. Not only does the adoption of digitalization improve efficiency and flexibility in urban water systems but also provides sophisticated novel services to the society with reduced costs [29]. In particular, these disruptive interventions have facilitated the real-time monitoring, optimization, and forecasting of freshwater consumption and pollution [30], either at a municipal level (e.g., [31]) or a residential/industrial one (e.g., [32], further serving as decision support tools [33]. It should be underlined that special emphasis has been placed on smart leakage detection as a part of sustainable water supply networks [34].

Within this context, the ultimate scope of this paper is to conduct a literature review analysis regarding the most current research efforts in the field of digital applications for urban water management to provide new insights on sustainable water use with the use of a systematic methodological approach adopted by Aivazidou et al. [35], Lampridi et al. [36], and Banias et al. [37]. More specifically, this study poses the following research questions (RQs):

- RQ#1: Which are the major smart technologies used for water management, focusing on freshwater consumption and pollution, at an urban level?
- RQ#2: How could these digital interventions foster urban water management in an efficient and sustainable manner?

With the use of a thorough systematic methodological framework, our review analysis presented herein finally explores 27 original research articles, mainly focusing on urban water supply and distribution issues. The papers under consideration are taxonomized into three major categories, as identified based on the extant literature, concerning the level of analysis (i.e., municipal or residential/industrial), the diverse digital technologies used (in response to RQ#1), as well as the research scope/focus (in response to RQ#2).

Overall, it should be highlighted that this review contributes towards providing a blueprint of best practices on incorporating digitalization in the domain of urban water stewardship and sustainability. The remainder of this study is structured as follows. In Section 2, the research design of the review is described and the articles' information (i.e., year, journal, country) is presented graphically. The main analysis of the literature about smart water management in urban contexts is performed in Section 3. Then, the major insights, along with the graphical representation of the articles' categorization statistics, are discussed in Section 4. Conclusions and future research directions are provided in Section 5.

2. Research Methodology

To perform the literature review in smart water management at an urban level, a combinative adaptation of the methodological approaches presented by Aivazidou et al. [35], Lampridi et al. [36], and Banias et al. [37] were followed and graphically presented in Figure 1. In this light, the steps of the proposed systematic methodological framework are illustrated in Figure 1. Initially, several search terms for analysis to retrieve a broader range of results were defined and rationally combined. The Scopus database was explored using the specified keywords and Boolean operators (AND/OR); indicatively, terms such

as "smart water technologies" or "digital technologies" were integrated with "water management" in an "urban" context to limit the searches with the relevant research area. In addition, the keywords' investigation was performed within the "Article Title, Abstract, Keywords" field in Scopus. The timespan was set from "2012" to "Present" to keep track of the most recent innovations of the 4th industrial revolution in the field of urban water management. Finally, only English-written peer-reviewed "Articles" (original research, e.g., case studies, modelling efforts) were considered.

Upon the completion of the preliminary search of a critical mass of scientific papers, the authors performed a detailed screening of the collected articles to create a shortlist for review. As the scope of this research is to identify digital technologies mainly related to the monitoring of freshwater consumption and pollution in water supply and distribution networks, any article principally focusing on the specialized topics of wastewater treatment, runoff/flooding, and urban gardening was considered out of the review's boundaries and thus excluded from the analysis. It should be noted that, although the terms "smart", "digital", and/or "urban" might be present on the title and/or abstract, publications with only a minor or theoretical focus on these issues, or partially referring to them, were also rejected. Duplicate articles were also eliminated from the list. To increase consistency, all articles were counterchecked. Based on the adopted methodology [35–37], a total of 27 articles were finally selected for review by 31st October 2021. Notably, the rather low number of remaining papers could be attributed to the fact that only few research efforts, as identified in the existing literature, deal with smart water technologies specifically targeted to urban water supplies.
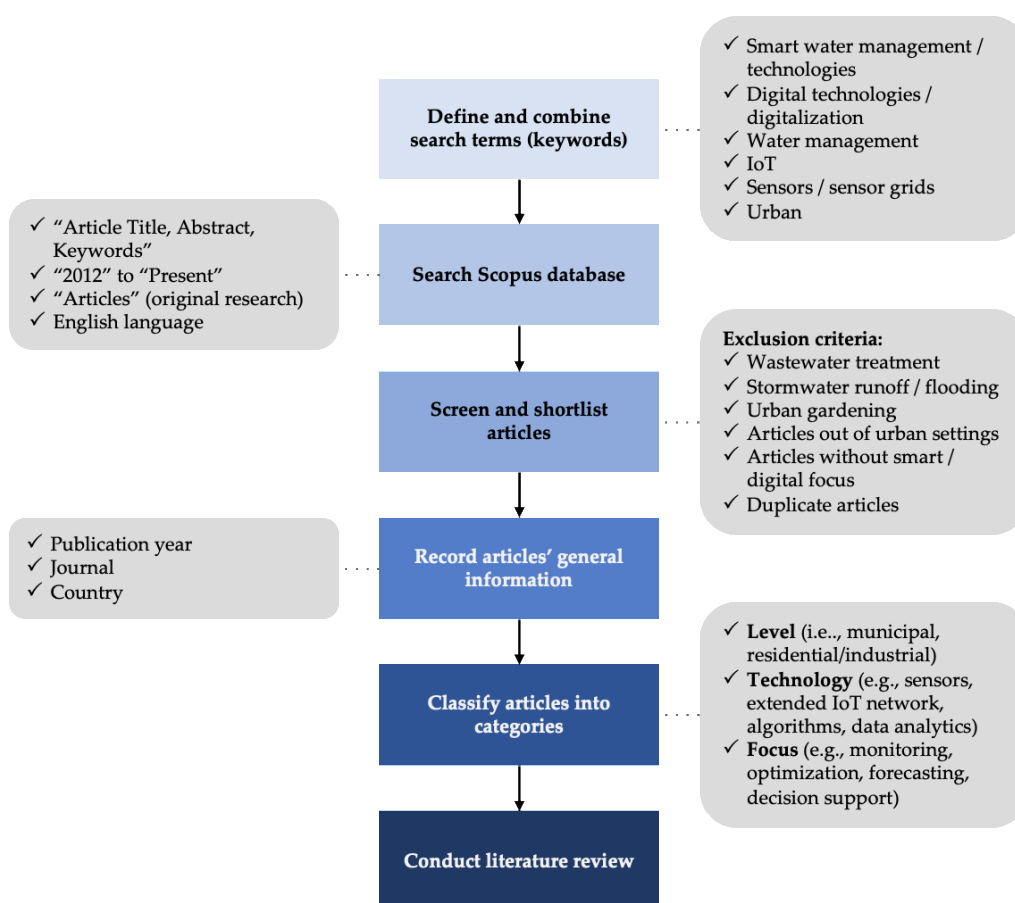
Figure 1. Systematic methodological framework (adapted from: Aivazidou et al. [35], Lampridi et al. [36], and Banias et al. [37]).

The biennial allocation of the articles over the last ten (10) years is depicted in Figure 2. It is evident that most research articles are accumulated in the last four years, following a rather exponential trend that highlights the accelerating evolution of digitalization. The distribution of the publications by journal is illustrated in Figure 3. It should be noted that the papers are scattered among various journal titles, mainly focusing on environmental and/or water-related issues, without any certain journal monopolizing the topic. The spatial coverage of the articles is graphically illustrated in Figure 4; if the location of the implementation case is not indicated, the country of the article's first author is used instead. More than half of the publications are performed in Europe, followed by Asian case studies. Notably, none of the collected research efforts has been identified in Africa or South America, highlighting a potentially existing gap between developed and developing countries.
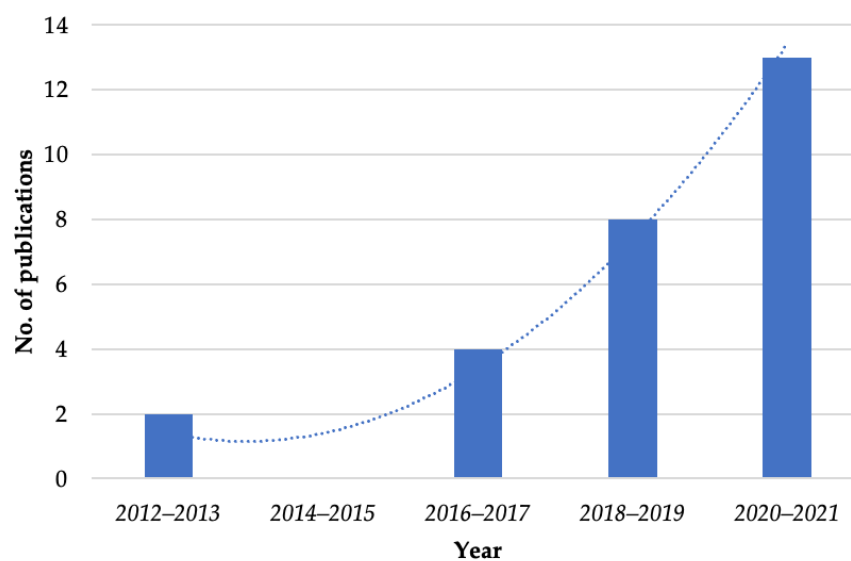

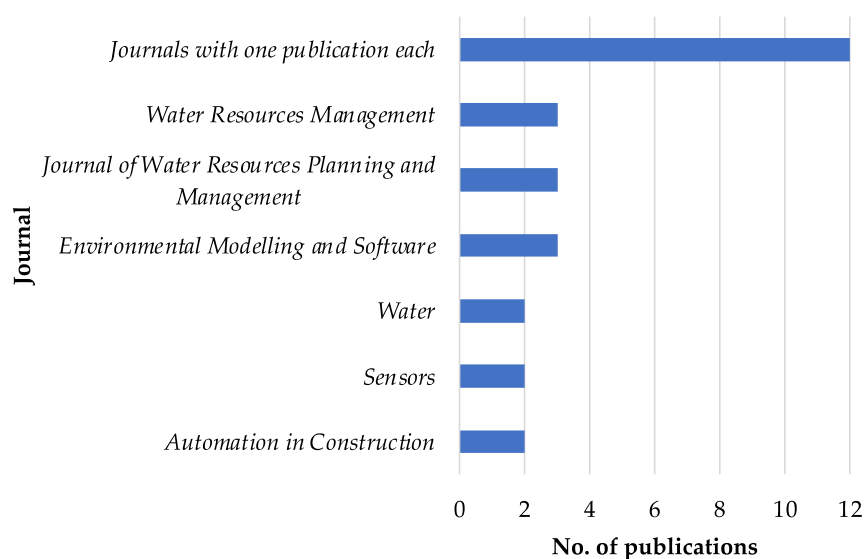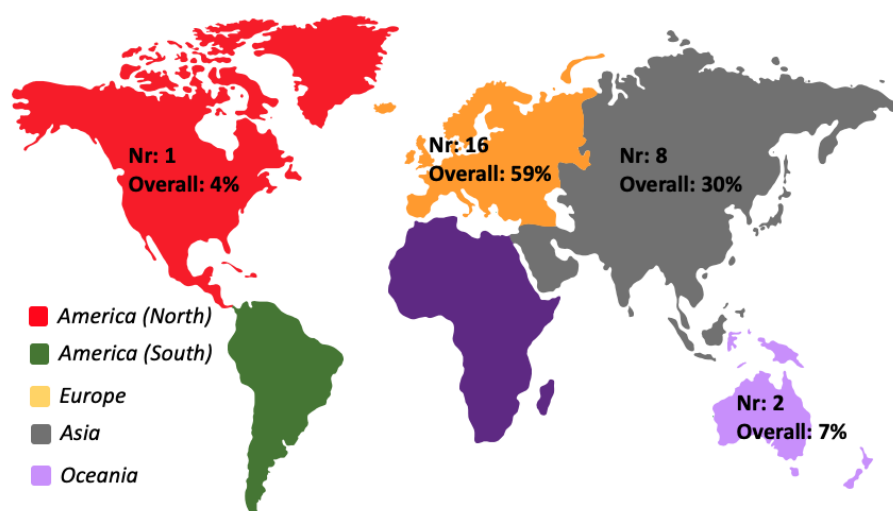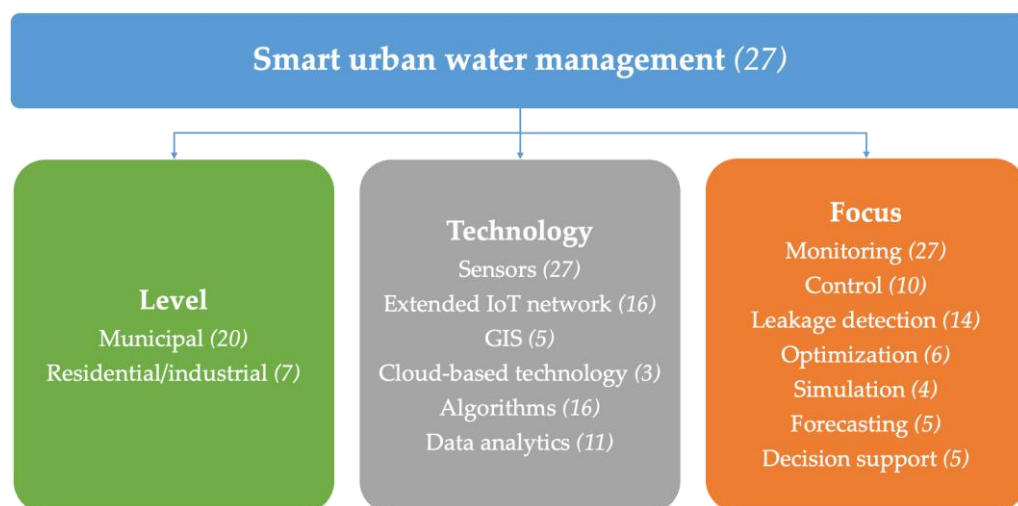**Figure 2.** Distribution of publications by two-year period.

Figure 3. Distribution of publications by journal.

Figure 4. Distribution of publications by continent.

Upon the completion of the general information recording, the articles were classified into three main categories/pillars: (i) level of analysis; (ii) technology used; and (iii) research scope/focus. More specifically, the level of analysis could be either municipal (i.e., city) or residential/industrial (i.e., building). In terms of digital technologies' use, emphasis was mainly placed on sensors and IoT networks, geographic information systems (GIS), algorithms (e.g., machine learning), and big data analytics. It should be noticed, regarding their scope, publications could be indicatively divided into monitoring and control, optimization, forecasting, and decision support applications. Figure 5 illustrates the distribution of papers among the three categories identified; the majority of papers refer to the municipal level, while all papers utilize sensors to monitor water use (consumption and/or pollution). Extended IoT networks and algorithms are commonly used, particularly in leakage detection procedures. More detailed and comparative (i.e., between the levels) statistics regarding technology and focus are provided in Section 4.

Figure 5. Distribution of publications by category.

3. Results

In this section, the analysis of the extant literature, divided by the level of analysis (i.e., municipal, or residential/industrial), is performed. Information about the scientific approach, the digital technologies used in urban water supply and distribution, and the major scope of each research article are provided in brief. Table 1 summarizes the basic distillation of the literature review analysis in a systematic approach according to the

three main categories (i.e., level, technology, focus). Table 2 provides a matrix of groups of papers belonging to the same categories. More specifically, the matrix summarizes the categorization of the papers under consideration in terms of the level of analysis along with the adopted technology and focus. It can be easily derived that most of the studies were utilizing sensors and IoT networks, data analytics, as well as algorithms, while the use of cloud-based technologies and GIS systems can be characterized as rather obsolete. Furthermore, except for monitoring, the majority of the papers focus on leakage detection, as it is one of the most important parameters for vulnerability assessment and risk management of infrastructure and critical facilities.

3.1. Municipal Level

In the work of Devasena et al. [38], an IoT-based water distribution system to monitor water flow was proposed, quantity, and leakage in an urban distribution system. Although the sensors were implemented at individual households, the analysis was performed and controlled centrally by the local municipality. Similarly, Slaný et al. [17] developed a smart metering network to monitor water usage and detect leakages. The network was firstly simulated in laboratory conditions to optimize its functionality and then put into real-world operation in a Czech municipality. From a more comprehensive perspective, Howell et al. [33] described the integration of a Semantic Web of Things with an IoT platform for smart water networks. The ontology and rule-based system allowed for seamless integration of sensors and comprehensive interpretation of lower- and higher-order knowledge. The proposed knowledge-based information system extended its functionality, is more scalable, and increased its interoperability capacity.

Notably, several authors have been particularly focused on leakage detection. A novel methodology was developed by Levinas et al. [32], using sensors and algorithms for predicting any leaking pipes in urban water distribution systems. The authors further performed computational data analytics to simulate the networks' performance. On top of this, Gong et al. [39] utilized smart water technologies, including accelerometers and algorithms, to monitor and detect cracks and leaks in urban distribution systems in a timely manner. Furthermore, Stephens et al. [40] implemented an acoustic sensors network for the early detection of leakages in an urban distribution network in Australia. The aim of the proposed IoT solution was to localize and repair cracks timely before the uncontrolled failure of the system.

Except for the technological perspective of digital leakage detection, several authors further targeted the sustainable benefits. Ramos et al. [41] developed smart water grids, modelled using GIS, to monitor and control water losses through identifying the urban network's leakages and cracks. The proposed IoT solution supported process optimization and decision-making for continuous improvement in terms of economic and sustainable (e.g., CO_2 emissions reduction) efficiency. Moreover, Geng et al. [42] created an algorithmic method for leakage detections based on sensor-monitoring data in complex water distribution networks. Compared with the other traditional methods, the proposed one is more effective in locating the leaky pipe and promoting sustainable water utilization.

Farah et al. [43] introduced a smart water network, capable of monitoring water usage, as well as identifying leakages. This is accomplished by the use of sensors and algorithmic analysis supports computing additional indices (e.g., minimum night flow), as well as analyzing operating hours flow rate. In addition, Farah and Shahrour [44] presented an innovative approach to leakage detection that is based on the traditional water balance and an enhanced minimum night flow implementation. The introduction of thresholds to the minimum night flow method exhibited highly positive results in the demonstration on the campus of Lille University, representing a small town. Farah and Shahrour [45] developed a smart metering system for timely leakage detection, implemented again in the same university. The review analysis presented herein highlighted that early identification of leaks can significantly reduce water losses and related costs.

Dealing mainly with algorithmic applications, Cristodoulou et al. [46] introduced a heuristic algorithm for sensor placement that performs a longitudinal optimization on entropy properties. By maximizing entropy in the system, sensor locations were determined, and, as the use case highlighted, nearly optimal solutions were reached, while water loss incidents were detected. The work of Comboul and Ghanem [47] contributed by developing and testing an algorithm dealing with the uncertainty of demand and sensor accuracy in water distribution networks monitored for quality. Intrusions, accidents, and contaminations were modeled by the algorithm to optimize sensor layout in the network. Results revealed that sensor layout was highly dependent on the demand hypothesis. Although imperfect sensor grids seemed more robust, they required a higher number of sensors to operate efficiently.

Additional smart water management solutions, mainly referring to water use and quality control, were identified at a municipal level. In the recent study of Oberascher et al. [48], a system that implemented smart rain barrels, as an IoT-based solution for rainwater harvesting, is introduced. The barrels included a network of sensors and controllers attached to open-source software to allow for efficient monitoring and generate simulation scenarios for water management. Although implemented at the household level, all digital rain barrels were centrally controlled by an Austrian municipality, acting as alternative storage units of the main urban water infrastructure. Amini et al. [49] attempted to create a smart framework to monitor, control, and manage groundwater wells and pumps using a combination of machine learning algorithms and statistical analysis. The authors finally proposed a forecast model to predict the water flow rate in Mashhad City wells in Iran. Finally, Llausàs et al. [50] utilized aerial imagery and remote sensing-based technologies to map residential swimming pools in the area of Barcelona to estimate the related water use. The authors further compared their results with cadastral data to support spatial planning.

In terms of water pollution detection, Chen and Han [51] implemented a wireless sensor network to monitor the water quality in the city of Bristol to enhance the efficiency of the city's water management system. At the same time, Castrillo and García [52] utilize variables that are commonly measured in-situ as surrogates to estimate the concentrations of nutrients in an urban catchment in England, making use of machine learning models, specifically random forests. Legin et al. [53] applied multisensory arrays to assess the urban water environmental safety, under diverse climatic and anthropogenic conditions, receiving samples from two different wastewater treatment plants in St. Petersburg. Focusing on smart sewage systems, Abbas et al. [54] utilized the campus of Lille University as a demonstrator of a smart city to monitor water used for drinking, sewage, electrical, and district heating networks. The analysis supported the numerical modelling and detection of eventual connections between the sewage and stormwater systems.

3.2. Residential/Industrial Level

At a residential level, Antzoulatos et al. [16] proposed an IoT network for monitoring and controlling water usage, as well as providing data analytics and management solutions to provide innovative solutions to consumers and water utility companies. The complete platform aimed to support decision-making in the field of urban water management. Similarly, Nie et al. [55] implemented smart water meters to monitor water quantity and quality to detect leakages or potential contamination. By retrieving data from sensors, they further use algorithms to perform data analysis. The proposed IoT network could allow both customers and companies to control water use in a proactive manner, take the correct decisions, and promote sustainable water supply. In a more integrated manner, Howell et al. [56] introduced semantic web technologies that provide connectivity between demand and supply of water for buildings and providers. The effective instantiation of domain ontology to the system, adding improved visualization and processing capacity, constituted the main innovation of this work.

Moreover, Gautam et al. [57] developed an IoT system to monitor water consumption (i.e., the water level in tanks) in an Indian urban housing complex. Ultrasonic sensors

retrieved the related data, while machine learning algorithms forecasted daily water requirements and leaking pipes. Rout et al. [58] developed an IoT protocol architecture including sensors and algorithms to monitor, analyze, and forecast water consumption and loss at a household level. The adopted methodology took into consideration weather data to provide a seasonal analysis. Further considering potential water pollution, Kalimuthu et al. [59] proposed a smart water management system to monitor and analyze both water quality and quantity in buildings, using sensors and algorithms. All data were gathered in the cloud-based systems to be utilized for data analytics. It should be underlined that this system could be expanded for each house at a municipal level. Emphasizing data analytics, Kofinas et al. [60] developed an algorithm capable of producing realistic and reliable synthetic household water usage data, serving the need to preserve the continuity of data for post-processing. The algorithm was tested on two highly differentiated use cases in two European countries with meaningful results.

Table 1. Systematic literature taxonomy of smart urban water management.

Article	Level		Technology						Focus						
	MU	RI	SE	IoT	GIS	CT	AL	DA	MO	CO	LD	OP	SI	FO	DS
Abbas et al. [54]	✓		✓		✓			✓	✓						
Amini et al. [49]	✓		✓				✓	✓	✓	✓				✓	✓
Antzoulatos et al. [16]		✓	✓	✓		✓		✓	✓	✓					✓
Castrillo and García [52]	✓		✓				✓	✓	✓					✓	
Chen and Han [51]	✓		✓	✓					✓						
Christodoulou et al. [46]	✓		✓		✓		✓		✓		✓	✓			
Comboul and Ghanem [47]	✓		✓				✓		✓			✓	✓		
Devasena et al. [38]	✓		✓	✓					✓	✓	✓				
Farah et al. [43]	✓		✓		✓		✓		✓	✓	✓				
Farah and Shahrour [44]	✓		✓	✓					✓			✓			
Farah and Shahrour [45]	✓		✓	✓					✓	✓	✓				
Gautam et al. [57]		✓	✓	✓			✓	✓	✓			✓		✓	
Geng et al. [42]	✓		✓				✓		✓			✓			
Gong et al. [39]	✓		✓	✓			✓		✓			✓			
Howell et al. [56]		✓	✓	✓	✓		✓	✓	✓	✓		✓			
Howell et al. [33]	✓		✓	✓			✓	✓	✓		✓	✓			✓
Kalimuthu et al. [59]		✓	✓	✓		✓	✓	✓	✓	✓					
Kofinas et al. [60]		✓	✓				✓	✓	✓					✓	
Legin et al. [53]	✓		✓						✓						
Levinas et al. [32]	✓		✓				✓	✓	✓		✓		✓		
Llausàs et al. [50]	✓		✓		✓				✓						
Nie et al. [55]		✓	✓	✓		✓	✓	✓	✓	✓	✓				✓
Oberascher et al. [48]	✓		✓	✓			✓		✓	✓			✓		
Ramos et al. [41]	✓		✓	✓	✓				✓	✓	✓	✓			✓
Rout et al. [58]		✓	✓	✓			✓	✓	✓					✓	
Slaný et al. [17]	✓		✓	✓					✓		✓	✓	✓		
Stephens et al. [40]	✓		✓	✓					✓			✓			

Level—MU: municipal; RI: residential/industrial; **Technology**—SE: sensors; IoT: Extended IoT network; GIS: geographic information systems; CT: cloud-based technology; AL: algorithms; DA: data analytics; **Focus**—MO: monitoring; CO: control; LD: leakage detection; OP: optimization; SI: simulation; FO: forecasting; DS: decision support.

Table 2. Group matrix of smart urban water management articles.

Level	Municipal	Residential/industrial
	Technology	
Sensors	All articles	
Extended IoT network	Abbas et al. [54]; Chen and Han [51]; Devasena et al. [38]; Farah and Shahrour [44]; Farah and Shahrour [45]; Gong et al. [39]; Howell et al. [33]; Oberascher et al. [48]; Ramos et al. [41]; Slaný et al. [17]; Stephens et al. [40]	Antzoulatos et al. [16]; Gautam et al. [57]; Howell et al. [56]; Kalimuthu et al. [59]; Nie et al. [55]; Rout et al. [58]
GIS	Christodoulou et al. [46]; Farah et al. [43]; Llausàs et al. [50]; Ramos et al. [41]	Howell et al. [56]
Cloud-based technology	No article	Antzoulatos et al. [16]; Kalimuthu et al. [59]; Nie et al. [55]
Algorithms	Christodoulou et al. [46]; Comboul and Ghanem [47]; Farah et al. [43]; Geng et al. [42]; Gong et al. [39]; Howell et al. [33]; Levinas et al. [32]; Oberascher et al. [48]	Gautam et al. [57]; Howell et al. [56]; Kalimuthu et al. [59]; Kofinas et al. [60]; Nie et al. [55]; Rout et al. [58]
Data analytics	Abbas et al. [54]; Amini et al. [49]; Castrillo and García [52]; Howell et al. [33]; Levinas et al. [32]	Antzoulatos et al. [16]; Gautam et al. [57]; Howell et al. [56]; Kalimuthu et al. [59]; Kofinas et al. [60]; Nie et al. [55]; Rout et al. [58]
	Focus	
Monitoring	All articles	
Control	Amini et al. [49]; Devasena et al. [38]; Farah et al. [43]; Farah and Shahrour [45]; Oberascher et al. [48]; Ramos et al. [41]	Antzoulatos et al. [16]; Howell et al. [56]; Kalimuthu et al. [59]; Nie et al. [55]
Leakage detection	Christodoulou et al. [46]; Devasena et al. [38]; Farah et al. [43]; Farah and Shahrour [44]; Farah and Shahrour [45]; Geng et al. [42]; Gong et al. [39]; Howell et al. [33]; Levinas et al. [32]; Ramos et al. [41]; Slaný et al. [17]; Stephens et al. [40]	Gautam et al. [57]; Nie et al. [55]
Optimization	Christodoulou et al. [46]; Comboul and Ghanem [47]; Howell et al. [33]; Ramos et al. [41]; Slaný et al. [17]	Howell et al. [56]
Simulation	Comboul and Ghanem [47]; Levinas et al. [32]; Oberascher et al. [48]; Slaný et al. [17]	No article
Forecasting	Amini et al. [49]; Castrillo and García [52]	Gautam et al. [57]; Kofinas et al. [60]; Rout et al. [58]
Decision support	Amini et al. [49]; Howell et al. [33]; Ramos et al. [41]	Antzoulatos et al. [16]; Nie et al. [55]

4. Discussion and Insights

The distribution of the collected articles (27) by type of technologies used and level of analysis is graphically illustrated in Figure 6. Special emphasis is given on the municipal level; in fact, about 74% (20) of the publications refer to the municipal level, while the rest 26% (7) focuses on the residential/industrial one. With respect to the municipal level (green bars), all related publications (20) utilize sensors, validating experimental outcomes that propose sensor grids as an indispensable part of urban smart water systems [61]. It should be noted that half of the papers (10) propose the implementation of an extended IoT architecture. Interestingly, another 50% (10) of the studies develop algorithms, such as machine learning, to support smart water management in urban settings, confirming that machine learning has emerged as a crucial digital technology in engineered water system applications [62]. Only 4 out of 23 articles employ the GIS or perform data analytics (e.g., big data techniques), mainly to foster optimization and forecasting applications. It should be underlined that none of the municipal-level publications utilized cloud-based technologies for data management.
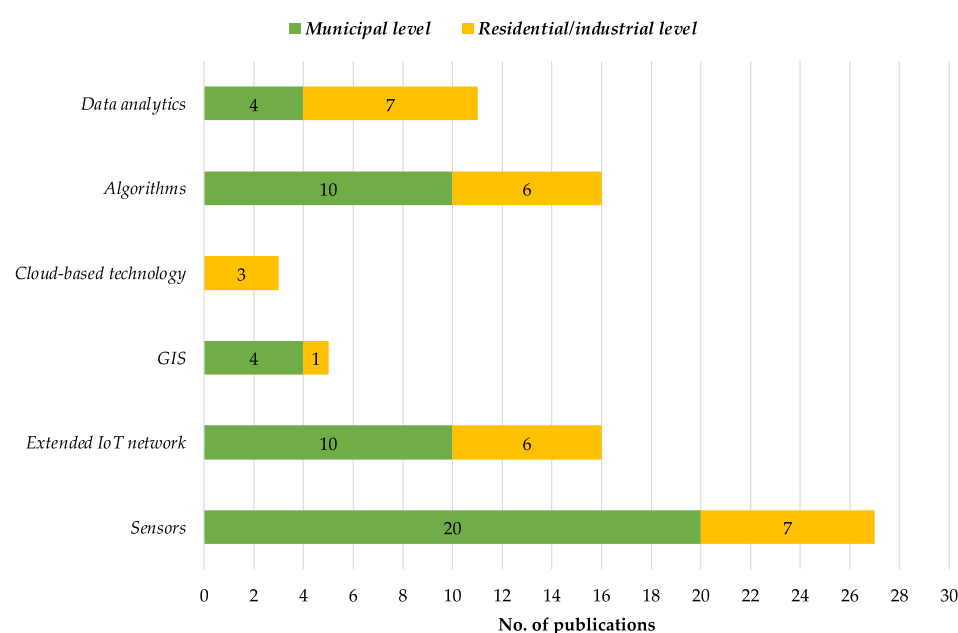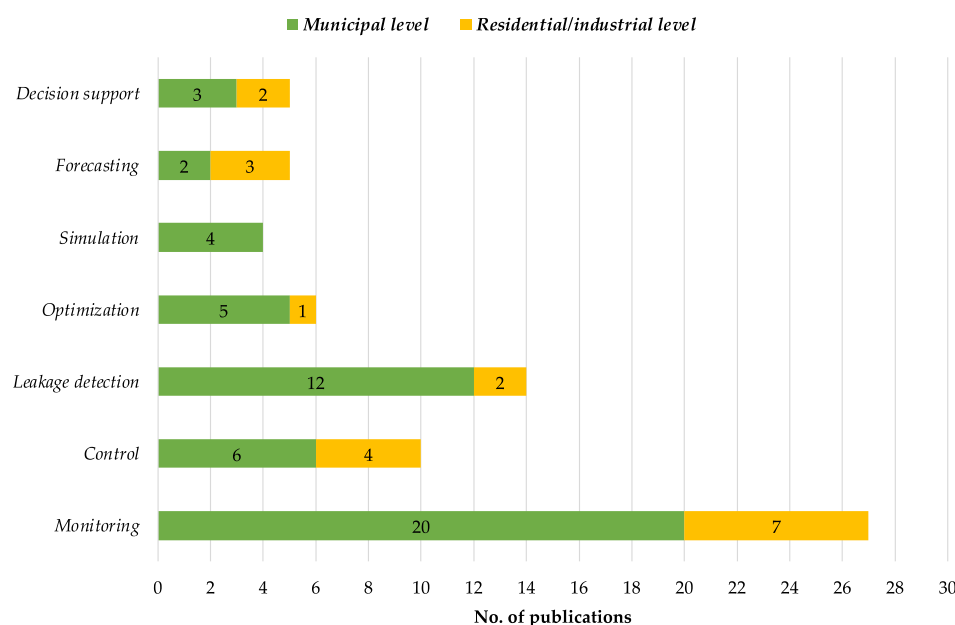
Figure 6. Distribution of publications by technology used and analysis level.

The distribution of papers at the residential/industrial level (yellow bars) follows a rather different pattern. Not only do all papers (7) implement sensors, but also 85% (6) of them deal with complete IoT networks. Notably, the same percentage of articles (6) propose algorithms for residential smart water management, while all studies (7) utilize data analytics methods. 3 out of 7 publications refer to cloud-based technologies, whereas only one uses GIS. To compare the two levels of analysis in terms of the adopted technology, apart from sensors that are present in all papers, IoT networks and algorithms seem to be further spotted in several articles of both categories. However, data analytics seem to monopolize the residential-level research compared to the municipal-level one, attesting that, along with machine learning, data analysis methods support smart water metering in residential blocks [26]. Furthermore, GIS is more common at the municipal level, whereas cloud-based technologies are used only at the residential level. Overall, further considering the municipal-level insights, the findings verify that smart urban water systems are mainly based on sensors' feedback and computer algorithms to analyze data to propose water management actions [24].

With respect to the research scope/focus (Figure 7), all research articles (27) of both municipal and residential/industrial levels emphasize monitoring applications of water quantity (e.g., consumption, loss) and/or quality (e.g., pollution) through sensors. It has been revealed that monitoring is followed by leakage detections; in fact, although the identification of leaks and cracks could be included in the monitoring case, it is separately reported given the fact that it is mentioned independently in numerous research articles for risk assessment or preventive maintenance purposes [20]. More specifically, 60% (12) of the municipal-level publications refer to leakage detection compared to only 29% (2) of the residential-level ones. Monitoring is usually combined with control processes to check whether monitoring data are in agreement with certain targets; in particular, 30% (6) and 57% (4) of the articles referring to municipal and residential/industrial levels, respectively, perform controlling activities (e.g., through the use of microcontrollers), as they accompany sensor monitoring operations in water systems [63]. It should be noted that, although optimization and simulation processes are conducted in several municipal-level studies (i.e., 25% (5) and 20% (4) papers, respectively), only one paper in the residential/industrial level supports optimization procedures. In contrast, forecasting is mentioned in only 2 out of 20 municipal-level papers and 3 out of 7 residential-level publications, in line with the use of data analytics in this type of study. With respect to decision support systems, 3 municipal-oriented and 2 residential-oriented articles have been identified with the scope

of allowing for efficient decision-making, as well as improving the efficiency of urban water systems and reducing costs [29].

Figure 7. Distribution of publications by research focus and analysis level.

5. Conclusions

Nowadays, as water scarcity has been emerging as a critical environmental challenge, while urbanization has been accelerating, efficient water management in urban areas becomes of vital importance to ensure freshwater sustainability and security [18,64]. On the above basis, the digitalization of several economic activities is also gaining ground in the water sector [65,66]. Within this context, this study effectively contributes towards providing a guiding map of best available practices for smart water stewardship in urban supply and distribution networks (in response to RQ#1) to explore how digital technologies have catalyzed water management both sustainably and efficiently (in response to RQ#2). To that end, the systematic literature review analysis presented herein aims to classify the collected publications according to their level of analysis, technologies used, and research scope/focus. The results revealed that the use of sensors and IoT networks monopolize both municipal and residential/industrial water management, mainly for water quantity/quality monitoring and leakage detection. Algorithms, such as machine learning, are widely used in both levels for optimization purposes. Data analytics are mainly conducted at the residential/industrial level to support forecasting and effective decision-making.

It should be highlighted that this review analysis presented herein acts as a first-effort review of the most pertinent state-of-the-art studies in the intersection of digitalization and urban water management. Thus, future research efforts should provide a more detailed techno-economic and environmental analysis of the smart technologies (e.g., sensors) that receive major attention in the field of urban water monitoring. In addition, the digitalization-oriented analysis may be extended in additional areas, such as urban wastewater treatment (e.g., [67]), drinking water supply (e.g., [68]) or flooding prevention (e.g., [69]), that were considered beyond the scope of the current research. Building upon similar frameworks for smart water stewardship in agri-food systems (e.g., [70]), ensuing research should focus on developing a comprehensive framework for digital urban water management, to assist decision- and/or policy-makers in selecting the optimal technological interventions for efficiently monitoring and forecasting water use in urban settings. Notably, these novel frameworks could further consider citizens' engagement in smart water monitoring to foster participatory water management [71]. Finally, cybersecurity and

other legal issues, indicatively referring to big data use, should be also studied to safeguard the reliability and viability of smart urban water management systems [72,73].

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