

Review

Building a Smart Water City: IoT Smart Water Technologies, Applications, and Future Directions

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Abstract: Water is an essential service for the sustainable development and economic competitiveness of any country. The global water demand has increased substantially due to economic development, climate change, and rising population. The Internet of Things (IoT) and Information and Communication Technologies (ICT) can help conserve available water resources. Smart cities apply IoT to boost the performance and efficiency of urban facilities. Smart cities are towns created to use IoT and ICT (innovative technologies) such as smart water applications. Several studies on smart water technology have been conducted, but there is a need to review current research that leverages the IoT as a communication technology to design effective smart water applications. This review paper is aimed at presenting evidence on the current design of smart water applications. The study also covers publication statistics to increase collaboration between stakeholders. Findings show that various technologies such as microcontrollers, embedded programming languages, sensors, communication modules, and protocols are used by researchers to accomplish their aim of designing IoT-based smart water solutions. None of the publications employed the 5G mobile networks as a communication module for their smart water application development. Findings further show that the integration of 3D printing and solar energy into IoT-based smart water applications is revolutionary and can increase the sustainability of the systems. Future directions required to ensure that developed smart water applications are widely adopted to help conserve and manage water resources are suggested.

Keywords: smart water system; IoT; smart water; water; smart water application; smart water technology; smart water meter; smart city; systematic literature review



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1. Introduction

Water is an essential service for the sustainable development and economic competitiveness of any country. The global water demand has increased substantially due to economic development, climate change, and rising population. As the world's population grows, so does the demand for more food, more water for agricultural purposes, and thus, more household usable water. About 40% of the world's population lives in regions with moderate to severe water stress. Two-thirds of the world's population (roughly 7 billion people) most likely resides in such water-stressed regions. Ironically, the world's freshwater system reduces due to pollution; and water use globally has increased six-fold over the past century, more than doubling the already precarious rate of population growth. It is easier to visualize the extent of water pollution considering that 70% of industrial waste and 90% of sewage are discharged untreated, which normally pollutes the supply of usable water [1]. The impact of climate change on water can affect all sectors of the economy, including tourism, agriculture, transportation, recreation, healthcare, industry, forestry, and fisheries [2]. For instance, in Nigeria, practically every urban area experiences water scarcity. The public water supply is intermittent, unreliable, and in most cases inaccessible, resulting in a high reliance on unsafe supplementary water sources which are prone to water-borne diseases such as dysentery and typhoid fever [3]. In South Africa, the Western

Cape has a semi-arid climate. Forecasts of climate change show that the province may experience more water scarcity with escalating temperatures, escalating evaporation, and escalating incidents of dangerous events such as droughts [4]. The demand for domestic and industrial water is rising, severely stressing the limited water supply available.

The Internet of Things (IoT) and Information and Communication Technologies (ICT) can help conserve available water resources. Smart cities have applied IoT to boost the performance and efficiency of urban facilities [5]. For instance, most definitions of smart cities lean towards the role of ICT. Peng et al. [6] describe smart cities as towns created to use advanced ICT (innovative technologies) such as smart meters, smartphones, mobile networks, sensors, and data storage technologies. The increased connectivity prompted a remarkable measure of information creation, which made possible a platform that allows data gathering, analysis, and distribution in various spheres of life [5]. A smart city integrates and monitors the state of every key infrastructure [7]. Furthermore, the goal of developing “smart cities” is to securely integrate different ICT solutions to help manage city resources. The definitions of a smart city highlighted so far show the importance of integrated information systems playing a significant role in offering innovative services in smart building, transportation, public safety, e-commerce, security, energy, education, healthcare, and environmental monitoring [8]. Environmental monitoring helps in identifying short to long term indicators of environmental health such as water leakage or wastage [9].

Within the literature, the idea of the smart water system is becoming increasingly popular in the field of urban water management, and different terms have also been associated to it. To aid in better comprehension of the concept, Table 1 provides definitions of smart water systems.

Table 1. Various definitions for smart water management systems.

Smart Water Definitions	Reference
The smart water system includes smart meters, smart valves, data communication, data fusion, data management, and analysis tools.	[10]
The smart water network would include smart meters, smart pumps, and smart valves.	[11]
The smart water grid is founded on IoT and the smart water system’s architecture.	[12]
The smart water system demonstrates the different ways technology, software, and middleware increase the benefit of smart metering data for stakeholders.	[13]
Smart water management differs from the traditional method of water management because it integrates ICT and water management technologies.	[14]
An innovative smart water supply system that integrates ICT into the water supply network.	[15]
The smart water grid incorporates ICTs into the water management distribution system.	[16]
Smart water system uses data-driven components to assist in the operation and management of a physical pipe network.	[17]

In smart water systems, there can be progress via smart water metering. Smart water metering encompasses two precise elements, meters that employ modern technology to gather data on water use and communication systems that can gather and transmit information on water usage in real time [18]. Smart water meters can communicate collected information to a wide audience such as consumers, utility managers, and facility authorities [18]. For example, Britton et al. [19] emphasized in their study the benefit of smart water meters on leak detection and repair. Morote and Hernández-Hernández [20] report that since the installation of smart water meters in 2011 and increased surveillance by water company employees in Alicante, Spain, the detection of unauthorized domestic water use (theft) has increased. According to their report, water theft decreased by 80% between 2013 and 2017. Monks et al. [21] note that smart water meters could provide environmental benefits such as a reduced carbon footprint of water supply systems due to water savings.

Figure 1 depicts an overview of smart water metering system architecture. The architecture is based on three layers. These layers include the measurement layer, the communication layer, and the user layer.

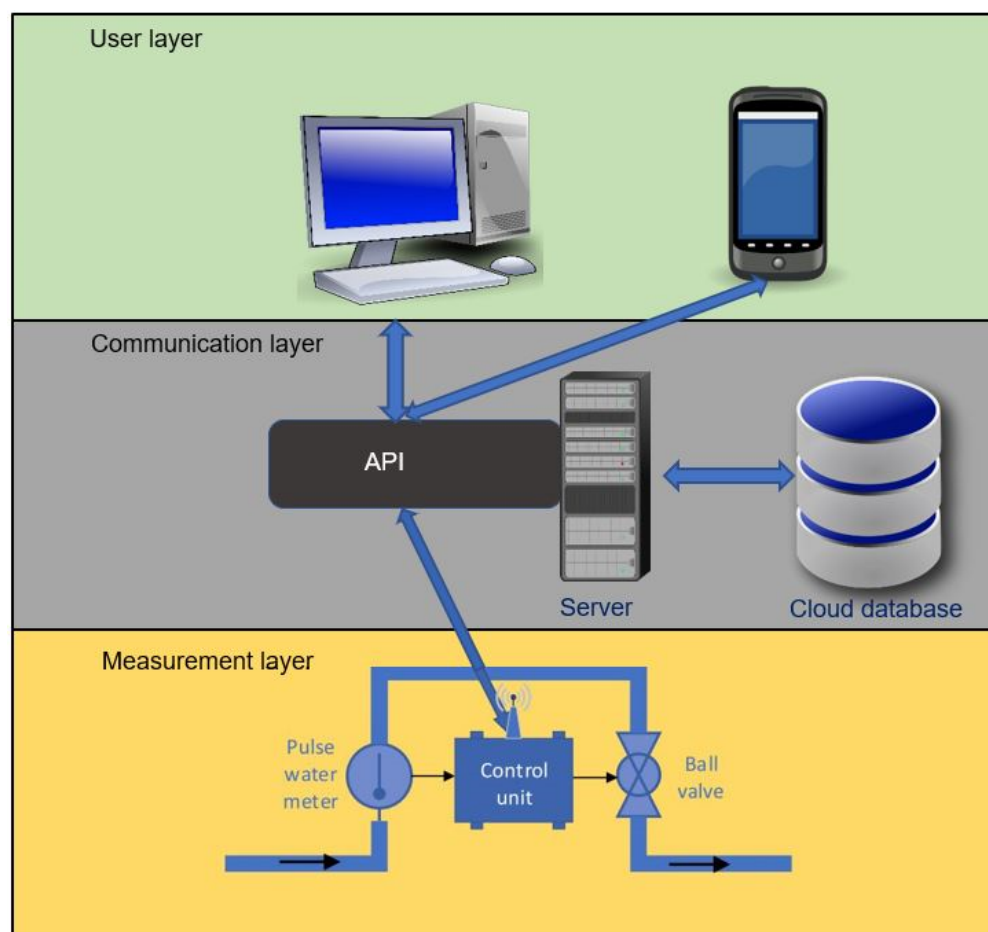


Figure 1. Overview of smart water metering system [22].

- The measurement layer consists of the pulse water meter, control unit, and ball valve. The pulse water meter gives information on the volume and consistency of water flow. Any pulse water meter may be used (irrespective of the number of pulses per litre). The central control unit (CPU) receives information regarding the water flow rate from the water meter, uses a wireless network for communication within the application interface, evaluates the water flow periodically using established rules in line with application logic, and controls the two-way valve. Any microcontroller can be used. The two-way ball valve controls the opening or closing of the water flow, which responds to requests from the control unit.
- The communication layer provides an application interface (API) with access to the cloud database. The API is implemented as a web service, and it allows communication between the smart water meter and the customer. There are three parts to the communication interface: communication with the sensor, ball valve, and mobile API.
- Two applications exist in the user layer. Firstly, the web application enables remote configuration, management of the water meter, and user administration. The second application is designed for mobile devices with a more intuitive and user-friendly experience [22].

Although review studies related to smart water systems have been carried out [23–26], a review of the current research that leverages the IoT as a communication technology to design effective smart water applications is needed. This paper reviews several components

and methods for IoT-based water management systems such as microcontrollers, sensors, and communication modules. The paper aims to present a list of current research on the design of smart water applications for water management, and cover statistics on research publications in this area, to determine areas that need future research.

The remainder of the paper is structured as follows: Section 2 presents an overview of IoT with technologies that enable IoT devices to sense and respond in varied conditions, while Section 3 presents the real-world applications of smart water technologies. Section 4 discusses the review methods adopted for this study. Section 5 presents the results, with the discussion and recommendations for future research in Section 6. Section 7 is the study's limitations, and Section 8 concludes the paper.

2. Internet of Things (IoT)

IoT has generally been regarded as an essential platform for achieving sustainable smart cities [27]. Kevin Ashton originally conceived the phrase IoT in the year 1999 [28]. The setting was based on supply chain management. However, as technology advanced, the meaning of “Things” has changed. The principal objective of creating a computer that senses information without a person's intervention remains. It is a fundamental transformation of the existing Internet to a network of interconnected objects, that gathers data from its environment and communicates with the physical world. Additionally, it uses the current Internet standards to offer services for data transfer, applications, analytics, and communications [29]. Simply put, IoT is when daily physical things are enhanced with sensing, computing, and communication abilities such that they can connect to the internet. These physical things, which communicate with the digital world, produce data and information that were not possible before [30].

2.1. Microcontroller and Sensors

According to Teja, a sensor is an input device that produces an output concerning its input. The term “input device” means that a sensor is a component of a larger system that provides input to a key control system such as a microcontroller or processor [31]. A microcontroller is a programmable device [32].

Sensors are devices that detect and react to specific inputs from the physical world. The input can be pressure, temperature, or other types of environmental phenomena. The output is a signal, converted to a readable format or communicated electronically via a link for humans to read [33]. Additionally, data generated by sensors are sent to a cloud server via the Internet, where they are analyzed, processed, and then sent to a terminal for users to consult [34]. In summary, a sensor is a detector that can sense changes in its environment and send information regarding that change. Different kinds of sensors exist such as water flow, ultrasonic, turbidity, flow rate, pressure, temperature, residual chlorine, water PH, water conductivity, Chlorophyll, and soil moisture. These sensors can be installed on pumps or pipes to continuously monitor water flow, levels, temperature, or quality in real time.

2.2. Wireless Communication Technology

2.2.1. Short Range Wireless Communication Technologies

There are several wireless communication technologies with transmission ranges between 1 and 500 m that fall under the category of short range. Bluetooth, ZigBee, and Wi-Fi are short-range communication protocols. These technologies are mainly used in the vicinity of buildings because of their limited range. For more details, consult the relevant literature [35,36].

ZigBee is used in industrial monitoring and smart home applications [37]. Wi-Fi is frequently used in public to provide mobile devices with a broadband internet connection with high data rates [35]. The Wi-Fi networks can easily be integrated with microcontrollers for remote access, data download, and water monitoring from other computers [38,39].

2.2.2. Long Range Wireless Communication Technologies

For long-range communication, cellular communication networks are widely used. There are five generations of cellular communication, namely 1G, 2G (e.g., global system for mobile communications (GSM), general packet radio service (GPRS)), 3G (e.g., universal mobile telecommunications system (UMTS)), 4G (e.g., long term evolution (LTE)), and fifth generation (5G) [36,40,41]. The 5G network is designed to meet IoT requirements for future smart cities by offering high data rates, lower latency for real-time applications, and many connected devices [41]. Cellular communication networks have a wide coverage area, making installation in remote locations simple. Cellular technology also enables two-way communication. Urban water infrastructure is frequently monitored and controlled using 2G technologies (GSM, GPRS) [42–44].

Furthermore, other long-range communication networks that promise to solve issues confronted with communication technologies in IoT applications are the low-power wide area networks (LPWAN). In general, there are two types of LPWAN, unlicensed and licensed. The most currently used LPWAN technologies in smart water applications are reviewed below.

Unlicensed LPWAN

The unlicensed LPWAN technologies are those that use unlicensed spectrum resources in the industrial, scientific, and medical (ISM) bands. Unlicensed LPWAN providers do not have to pay for spectrum licensing because they use the unlicensed band, which lowers the cost of deployment. The two main competitors for unlicensed LPWAN are LoRa and Sigfox [45,46].

- **LoRa:** LoRa means long range. It is a physical layer LPWAN solution created and patented by the Semtech Corporation that modulates signals using a spread spectrum technique [47]. LoRa uses the chirp spread spectrum (CSS) modulation, which spreads a narrow-band signal over a larger channel bandwidth, allowing for high interference resilience while also lowering the signal-to-noise-and-interference ratio (SINR) needed at a receiver for proper data decoding [48]. The CSS spreading factor can range from 7 to 12, allowing for variable data rates and tradeoffs between throughput and link robustness, coverage range, or energy consumption. The data rate of LoRa can range from 50 bps to 300 kbps, depending on the spreading factor and channel bandwidth [49,50]. The LoRa-based communication protocol known as LoRaWAN networks uses a star-of-stars topology, with gateway devices relaying messages between end devices and network servers. LoRaWAN has three classes of devices (Class A, B, and C) with varying capabilities. Class A LoRaWAN devices have the lowest power consumption and only require short downlink communication, and they use pure-ALOHA RA for the uplink. Class B devices are made for applications requiring more downlink transmission demands. Class C devices, on the other hand, continuously receive slots, meaning they constantly listen to the channel apart from when they need to transmit. Out of the three LoRaWAN classes, all the devices need to be compatible with Class A [51]. Smart water technologies like sensor nodes and water meters are often installed in harsh environments and rely solely on batteries for power. LoRaWAN provides low power consumption (battery life can last up to ten years), allowing these devices to operate for as long as possible. Furthermore, the LoRaWAN protocol offers long communication ranges (1–5 km in urban areas and up to 15 km in rural areas) and excellent penetration for underground communications. As a result, LoRaWAN offers enormous opportunities. LoRaWAN networks can be used for various smart water applications, including smart water quality monitoring, smart water metering, and leak detection [36].
- **SigFox:** Another popular unlicensed LPWAN solution available is SigFox. SigFox suggests using ultra narrow-band (UNB) technology for transmission with a bandwidth of only 100 Hz for extremely short-payload transmission. Sigfox technology allows for lower power consumption devices and offers wider coverage than LoRa, at a lower cost data rate [52]. When Sigfox was first released, it could only support

uplink communication; but, over time, it developed into a bidirectional technology that has a sizable asymmetry link [53]. However, only after an uplink transmission can the downlink transmission be initiated. Furthermore, the number of uplink messages per day is limited to 140, and each uplink message can only have a maximum payload length of 12 bytes [50]. Owing to these rigid limitations and an unopened business network model [49], academia and industry have turned their attention away from Sigfox to its competitor LoRaWAN, which is regarded as being more open and flexible.

Licensed LPWAN

The licensed LPWAN describes LPWAN technologies that make use of licensed spectrum resources. The two most promising standards for licensed LPWAN are long-term evolution machine-type communications (LTE-M) and narrow-band IoT (NB-IoT). Here is a brief review of the two licensed LPWAN technologies for long-range connectivity.

- **LTE-M:** LTE-M and existing cellular networks are completely compatible [54]. It can be viewed as a simplified form of LTE designed for Internet of Things applications requiring low power consumption and low device cost [55]. LTE-M technology supports mobile MTC (machine-type communications) use cases and voice-over networks [56]. In the downlink of LTE-M, multi-tone single-carrier frequency-division multiple access (SC-FDMA) is used, and in the uplink, orthogonal frequency division multiple access (OFDMA) is used. To reduce the cost of hardware and complexity, LTE-M has a 1.4 MHz bandwidth and usually supports half-duplex operations (full-duplex operations are also allowed) and one receive antenna chain. New features were proposed for the Third Generation Partnership Project (3GPP) Rel-14 and Rel-15 to improve LTE-M performance in terms of positioning, data rate, latency, and voice coverage.
- **Narrow-band IoT (NB-IoT):** NB-IoT is also known as long-term evolution (LTE) Cat NB1. It is an LPWAN technology that coexists with cellular networks, specifically LTE and GSM. When compared to existing cellular networks, NB-IoT has a long communication range, long battery life (up to 10 years), high penetration, and low data rates. NB-IoT uses a frequency bandwidth of 200 kHz, which is equivalent to one physical resource block in LTE and GSM transmission [57]. With a frequency bandwidth of 200 kHz, NB-IoT can function in three different modes as follows: stand-alone operation (the NB-IoT can connect to one or more existing GSM carriers); guard-band operation (using unused resource blocks in the LTE spectrum guard-band); in-band operation (use of resource blocks in an LTE carrier). NB-IoT reuses several LTE functionalities and adapts them to meet the needs of IoT applications. For example, NB-IoT uses the LTE back-end system to broadcast valid messages to all end devices (EDs) in a cell. The data rates for uplink and downlink communications are 200 kbps and 20 kbps, respectively [58]. Each message has a maximum payload of 1600 bytes. Data communication uses QPSK modulation. Precisely, downlink communication uses OFDMA, whereas uplink transmission uses SC-FDMA modulation. NB-IoT has several advantages for smart water applications, particularly its low power consumption, long communication range, and excellent penetration. NB-IoT has demonstrated benefits in some smart water applications. Huawei and Vodafone used NB-IoT to send data to an end device that was installed in a water meter [53]. Finally, NB-IoT is preferred for smart water applications because of its extremely low power consumption. Table 2 below provides a summary of the discussed technical parameters of LPWAN.

2.3. Method for Real-Time Data Analysis

This section enables water utilities to reach conclusions by using data provided by sensing devices. It is the foundation of smart water applications due to its ability to make decisions based on collected data.

Table 2. Summary of technical parameters of LPWAN: LoRa, SigFox, LTE-M and NB-IoT [50,51,56,59,60].

	LoRa	SigFox	LTE-M	NB-IoT
Topology	Star	Star	Star	Star
Frequency	Unlicensed ISM bands	Unlicensed ISM bands	Licensed LTM bands	Licensed LTM bands
Bandwidth	125 kHz and 250 kHz	100 Hz	1.4 MHz	200 kHz
Bidirectional	Half-duplex	Limited/Half-duplex	Full/ Half-duplex	Half-duplex
Maximum data rate	50 kbps	100 bps	1 Mbps	250 kbps
Maximum payload length	243 bytes	12 bytes	1000 bits	1000 bits
Link budget	164 dB	156 dB	153 dB	164 dB
Coverage	Urban (5 km), rural (20 km)	Urban (10 km), rural (50 km)	Few kilometers	Urban (1 km), rural (10 km)
Localisation	Yes	Yes	Yes	Yes
Mobility	Yes	No	Yes	Yes
Inference immunity	High	Very high	Low	Low
Battery life	10 years	10 years	10 years	10 years

Researchers are paying more attention to machine learning (ML), which can be used as a data analysis strategy in smart water applications. Machine learning is a field of artificial intelligence that allows systems to learn automatically from a set of data without explicit programming. Machine learning methods are classified under supervised learning, unsupervised learning, and reinforcement learning. In supervised learning, the learning agent aims to learn a general rule that maps inputs to outputs, using example inputs and desired outputs from the labeled data set. Examples of supervised learning algorithms are Support Vector Machine and K Nearest Neighbor. Unsupervised learning aims to identify a function that will disclose a hidden structure from unlabeled data. The K-Means Clustering Algorithm is commonly used in unsupervised algorithms. Reinforcement learning aims to enhance a long-term goal by interacting with the environment through a trial-and-error process [61].

Machine learning can play an important role in smart water applications. Currently, some machine learning algorithms have been used in smart water management. For more details, consult the relevant literature [62–67].

2.4. Software for Data Management

After data are transmitted, they need to be stored, analyzed, and presented coherently. These data could be stored in the cloud for example MySQL database, and data visualization software such as JAVA platform [22], Grafana [68], and Python can be used for data presentation.

3. Real-World Applications of Smart Water Technologies

Smart water technologies are increasingly being implemented around the world to help save water and combat the effects of climate change. In the study conducted by Okoli and Kabas [69], the authors identified cities that have successfully implemented these systems. For instance, Aigües de Barcelona in Spain implemented smart water meters to address climate change and droughts. This reduced the costs for manual reading, fraud risks, and improved customer behaviour towards water saving, as well as reduced overconsumption alerts from 9% to 3%. Real-time data also enhanced network management and billing transparency [70].

Singapore's National Water Agency (PUB) has been pursuing a smart water project due to the unreliable supply of water resources. In January 2022, 300,000 smart water meters were installed in residential and commercial properties. The PUB assured users that only data from water consumption would be recorded by a smart water meter and transmitted directly and securely to PUB [71].

Beal and Flynn [72] interviewed City West Water in Victoria, TasWater in Tasmania, Mackay Regional Council in Queensland, and the Water Corporation of Western Australia which had completed smart water projects to offer empirical insight into project benefits. The study revealed that these water companies enjoy benefits such as decreased operating costs, enhanced customer service, increased accuracy, and water savings of over a gigalitre, demonstrating the benefits of smart water projects.

The case study by Jagtap et al. [73] on the successful implementation of an IoT-based real-time water monitoring system in a food beverage factory revealed significant improvements in water sustainability. The system revealed detailed information on water consumption and gave insights into water hotspots needing maintenance. The action led to an 11% reduction in daily water usage, demonstrating the potential of water-saving initiatives.

Finally, Okoli and Kabaso [69] identified several benefits and challenges associated with using smart water technology. Thus, future adopters can learn from cities that have already implemented these systems.

4. Methods

A systematic literature review of smart water metering systems was performed adopting the PRISMA statement approach [74], and the review process was inspired by [75].

The paper aims to present current research on the design of smart water applications for water management, as well as cover publication statistics on research in this area. The study will henceforth use "smart water meter" as the keyword unless otherwise stated. This covers all efforts from using ICT and IoT to positively improve the efficiency of water management for a sustainable future.

4.1. Research Questions

1. *What are the current smart water application designs for water management?* The objective is to identify the current smart water application techniques used in managing water.
2. *How are these studies geographically distributed?* The objective is to examine and comprehend the publication statistics of the studies to increase collaboration between stakeholders.

4.2. Search Strategy

In the search for publications, the following online databases were consulted: ACM Digital Library, EBSCOhost, Scopus, and Google Scholar. Google Scholar provided articles that had previously been covered by these databases, but it also served as a relevant software to locate publications that had been published in other venues or databases. Searching Google Scholar with identified search strings resulted in a high number of articles that were not appropriate due to the aim of this paper. The search was also restricted to titles, abstracts, and keywords that satisfied the inclusion criteria. The following search strings were used in the search:

("Smart water meter" OR "IoT Smart water metering" OR "Smart Water Metering" OR "Digital water") AND (System OR Technology OR Framework OR Solution) AND (Adoption OR Implementation OR Uptake) AND (Factors OR Issues OR Challenges)).

4.3. Study Selection

The following criteria for inclusion and exclusion were applied in the selection of documents for this study:

1. Inclusion criteria:
 - Empirical studies on smart water meter systems and adoption factors.
 - Empirical studies using IoT techniques for water management.

- Empirical studies using ICT and water.
2. Exclusion criteria:
- Studies completed before 2005, or not conducted in English.
 - Review papers.

4.4. Data Quality Assessment

Table 3 displays eight quality assessment (QA) questions that were used for the review process. Scores were assigned as follows: 1 indicates complete satisfaction, 0.5 indicates partial satisfaction, and 0 (no) indicates if the study is unsatisfactory. Studies with quality assessment scores less than 4.0 out of 8.0 were rejected.

Table 3. Eight quality assessment questions used for the systematic review.

Quality Assessment Questions
Are the aims of the research clearly stated?
Are the independent variables defined?
Is the data-collection procedure clearly defined?
Are the techniques clearly defined?
Are the results and findings clearly stated?
Are the limitations of the study specified?
Is the research methodology repeatable?
Does the study contribute/add to the literature?

4.5. Data Extraction Form

Table 4 presents the data extraction form used. Data from studies that had been filtered based on QA criteria were extracted to complete the form fields. This was carried out to retrieve appropriate data for the subject matter.

Table 4. Sample form for data extraction.

Variables
Paper title:
Authors:
Type of Publication:
Year:
Study area:
Country of publication
Score for overall quality assessment (out of 8.0):
Microcontroller used
Sensors used
Embedded programming language used
Communication module
Strengths (solution)
Weaknesses

4.6. Data Synthesis

This study provides some key details that were extracted from the selected studies. Thus, the sections that follow hereafter present findings in textual, tabular, and statistical methods.

5. Results

Figure 2 displays the number of studies for each phase of the review process.

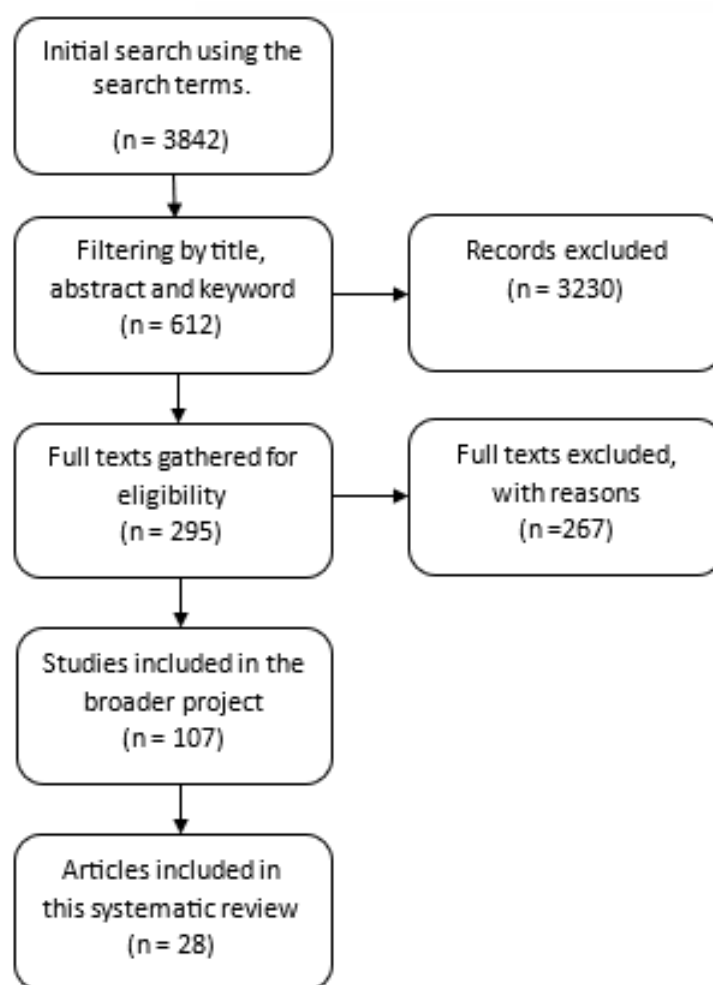


Figure 2. Outcomes of the review process.

This review is on research that leverages IoT as a communication technology to design smart water applications for water management. The findings for the research questions are summarized in the sections that follow.

5.1. What Are the Current Smart Water Application Design Techniques for Water Management?

Wong et al. [76] developed, calibrated, and deployed a water quality monitoring system that measures water level and turbidity at two-hour intervals. The low-cost 3D-printed IoT-based near-real-time water quality monitoring system was powered solely by a photovoltaic system, for two months in a palm oil plantation on Carey Island, Malaysia. The water quality monitoring system is made up of four components: energy, monitoring, time, and communication. To determine the ideal monitoring frequency, the electrical consumption values of the system during operating, data transmission, and standby modes were calculated. The proposed system shows a successful integration of IoT with 3D printing, low-cost sensors, and microcomputers. Further, the study showed the great possibility of using solar energy as the main source of energy for running low-power water quality monitoring systems in tropical nations.

Ntuli and Abu-Mahfouz [77] proposed a water management security architecture that will ensure secure booting, firmware updates, and communications. Nikhil et al. [78] proposed an IoT smart water quality monitoring system that is made up of a design board, a Wi-Fi module, sensors, and a computer. The system uses Things Speak to collect five water parameters from various sensors, including water level, water pH, turbidity, temperature,

and conductivity. The system uses less time and costs in detecting the water quality of a reservoir.

Yang et al. [79] developed a domestic water consumption monitoring system. The system monitors individuals' water consumption behaviour, that is, the time and amount of water consumed by each appliance in the household is recorded remotely and the data are saved in a database. It is a local database system that provides immediate pragmatic advice about saving water and classifies the water consumption behaviour of that person.

Gosavi et al. [80] demonstrated a paper on using Raspberry Pi and Arduino to monitor and forecast domestic water consumption over the Internet. The water flow rate is measured by a Hall Effect sensor-based flow meter. The Arduino, a microcontroller is connected to the flow meter, it collects and sends data to the Raspberry Pi, a microcomputer. The data are then uploaded by the Raspberry Pi to the cloud infrastructure, where a database is created. The web-based technology shows daily water consumption to users and water distributors. The leakage management, demand management, and asset management attributes of the water management system are also covered in this study.

Suresh et al. [81] proposed a system for water metering that uses low-cost IoT hardware and a custom-built smartphone application. The method allows both domestic and industrial water consumers to perform meter readings and update the database for billing and payment using normal smartphones. The proposed system overcomes drawbacks in some smart meter systems, such as tampering with pre-paid water meters that frequently go unnoticed because pre-paid meters are standalone devices. Tampering or unauthorized top-ups to prepaid meter smartcards are carried out using malicious software.

The study by Srivastava [82] proposed an independent system that could monitor water levels as well as stop water flow in a tank when it is full. The system (smart home server) receives a signal from the water level detecting sensors placed in the tank. It then switches off the water flow and notifies the user via their mobile phone.

Anandhavalli et al. [83] proposed a solution for water consumption using a water flow rate sensor and an interface with a Node MCU microcontroller embedded with Arduino code. The Arduino IDE software is utilized for Arduino coding to find the water flow rate, show the output on a serial monitor, and transfer sensed data to the cloud, where consumers can monitor it.

Gupta et al. [84] proposed a solution for water management in households and their solution monitors the water for basic quality standards. The project will assist water supervisors in taking the necessary actions if water levels drop below a certain threshold. The project primarily uses a turbidity sensor and an ultrasonic water level sensor. Turbidity sensors would monitor basic water quality features, and the ultrasonic water level sensor would constantly monitor the water level. Data are then transmitted to users via the cloud.

Soh et al. [85] designed a water consumption monitoring and alert system based on IoT Ubidots Cloud. It is designed to monitor water usage in households daily, weekly, and yearly in real time using mobile devices. It displays data using the Ubidots Dashboard, and when the data exceed a limit, an alert is sent to the home user.

De Paula et al. [86] proposed a solution for measuring water consumption, leakage detection, and water interruptions. The solution informed users about issues with water usage. The proposed solution can also switch off water distribution to prevent leakage. Data gathered by sensors are made accessible to devices and users via IoT middleware. A type of IoT middleware that makes use of the Publish/Subscribe architecture and the Message Queue Telemetry Transport (MQTT) protocol. The middleware stores, displays, and transmits data to other IoT devices that can perform automated actions on sensor data.

Hasibuan and Fahrianto [87] proposed an innovative low-cost solution that can predict water consumption for household activities. The water monitoring system integrates with the IoT concept. The water flow sensor connects to the NodeMCU 8266 microcontroller. Every water-related activity is transferred to an element termed dictionary activity (cloud storage). The dictionary activity examines the data gathered by the smart water system and ranks each water use activity according to category, from most to least water used. An

online portal allows users to view the water used. The proposed system can inform users of their daily water (litre) consumption for every activity within the house in real time, for instance, washing machines, washstands, and showers. The system is designed and expected to correctly predict water consumption activities. The importance of using the system is to raise individual awareness regarding water saving to ensure the sustainability of water resources.

Patel and Gaikwad [88] designed a low-cost remote monitoring system based on IoT. The system distributes equal water quantity based on geographical survey and population density, water quality, and the water flow rate is controlled to help solve water-related problems. Arduino collects data from sensors and then transmits the data to Raspberry Pi, which then controls the flow of water by changing the position of a stepper motor installed in the shaft of a manually operated control valve. End users can access a web-based automated meter reading system. End users only pay for the water they use, which reduces complaints.

Rapelli et al. [89] focused on water use in big complexes. They proposed a fully automated system capable of performing three distinct tasks such as distribution, monitoring, and billing. By implementing a billing system for individual water usage, water wastage is completely controlled. A cost-effective system that enables water and financial savings for the user. Alerts are occasionally sent on water consumption. The system helps meet the need to protect future generations from water scarcity.

Jisha et al. [90] proposed a system for domestic sectors and large agricultural fields, which is an IoT-based technical solution for water management that incorporates various sensors, cloud storage, and so on. Aside from decision-making methods such as automatic power cuts, the system sends relevant alert messages to users' smartphones when there is excessive water use. Therefore, it is beneficial to remotely monitor the water level in the soil and the water tank. This is an intelligent approach because of the system's alert mechanism and reliable diagnosis capabilities. The proposed system is designed to make water level monitoring easier for users, making it more user friendly.

Herath [91] focused on factors that contribute to a cumulatively significant impact on household water use. Water wastage is primarily caused by careless usage, overflow of overhead tanks, and leakages in households. Their "Smart Water Buddy" system uses IoT devices to monitor water use, detect water leakages, and abnormal usage using machine learning, which aids in optimizing the use.

Vithanage et al. [92] believe that for people to remain healthy, they need to drink enough water in the right amounts. However, it is difficult for many people due to their busy life schedules, and occasionally because of a scarcity of clean water. To help users manage everyday water needs and make sure they drink high-quality water, the "SmartOne water bottle" IoT-based smart bottle is proposed. The water bottle is made up of a mobile application and hardware, where the mobile application serves as the interface between the user and the bottle.

Harika et al. [93] describe a monitoring system which makes use of real-time water consumption data from water flow meters at residences to make useful inferences. For consumers, an effective dashboard is created by combining IoT, the Thingspeak cloud computing platform, and Android Studio. The goal of the proposed model is to instill in citizens a sense of responsibility by regularly tracking water usage using visually appealing charts, showing monthly water utility costs, and offering guidance in the form of a small Android application on their phones. It helps users know where water is being wasted and consumed the most, which helps them make proactive decisions and save water resources.

Ray and Goswami [94] proposed an IoT-based smart water meter, and Cloud computing equipped with machine learning algorithms. The system can be used to distinguish between excessive and normal water usage in households, industries, and sectors that use large amounts of water. With ease of data monitoring and visualization, the smart water metering system can be used to detect water leakages and excessive water consumption. Their proposed server-less architecture may easily be implemented on a large scale.

Ray and Ray [95] proposed a system for generating authentic data for water use patterns using machine learning to detect normal or excess water flow via a pipe. The architecture can be scaled up for more functionalities. Collected data are always encrypted end to end for confidentiality and security of water usage patterns. The system is user-friendly, with the introduction of water tariffs, making individuals accountable for their water use.

Sarangi [96] proposed a system that can help detect water theft and leakage problems faced by the government. The system will monitor water leaks in real time and allow relevant authorities to take necessary actions to reduce water loss. The proposed approach offers the concept and definition of wireless networking technologies, and the flow sensors help stop water leakage and theft.

Ranjan et al. [97] presented an IoT-based model of smart rainwater harvesting. The model is made up of a structure with separation that divides two tanks in a 60–40% ratio. To determine whether it is raining or not, a sensor that detects rainfall is fixed on top of the structure. A pH sensor decides the pH value of the rainwater, and if it is greater than 5, the servo motor mounted on a hinge rotates clockwise to fill the tank on the right side. If the pH of the water is below 5, the hinge rotates anticlockwise to fill the tank on the left side. Acidic water (pH less than 5) is separated from potable water (pH 5 or higher) using this process. This was all possible with the NodeMCU Wi-Fi module.

Alves Coelho et al. [98] proposed a wireless sensor network-based system that detects water leaks with 75% accuracy, using an autonomous learning algorithm. The ESP32 microcontroller was used, with 32 general-purpose input/output ports, 12 analogue ports, and power efficiency. LoRa was implemented using an RMF95W module, and an aggregation node using Narrowband-Internet of Things (NB-IoT) was installed. The MQTT protocol was selected for its architecture and lower power consumption.

Fuentes and Mauricio [99] presented a smart system for measuring water consumption with high levels of decoupling and integration of different technologies that allow for real-time visualization of water consumption. The system collects data via a smart meter, and is pre-processed by a local server (gateway), then sent to the cloud regularly to be analyzed by a leak detection algorithm and is accessible via a web interface. The system's accuracy, recall, and precision to detect leaks are all 100% according to the authors, who also noted that its error margin is 4.63%.

Migabo et al. [100] proposed an IoT-based smart water meter that can operate for the required 10 years using the long-range wide area network (LoRaWAN). The system makes use of a Silicon laboratory microcontroller, whose firmware manages the energy modes and state transitions between them based on the required task. Included is a LoRa Technology SX1272 low-power radio frequency (RF) transceiver 860–1000 MHz. The design employs a radio frequency switch to choose between radio frequency communications between the consumer user interface and LoRa IoT communications over long distances with a LoRa gateway in its dual radio frequency activities. The authors note that using the device in African municipalities is feasible given that it can last longer than 10 years.

Alejandrino et al. [101] proposed a smart water meter system that uses an IoT platform to deliver real-time reports on water consumption and billing. The system can run automated data collection and upload phases while the meter is not in use. Google Application Scripting (GAS) was used to connect the physical prototype, Google Sheets, and a mobile application. The MATLAB Curve Fitting Tool is used to generate a calibrated equation for determining water flow rate and consumption.

Ali et al. [102] developed a water distribution network abstraction prototype. The network has sensors installed to measure the desired physical quantities, such as water flow rates, turbidity, and pH levels. A sensor network is created to transmit readings to the Firebase platform. An IoT testbed architecture is used to fully connect all IoT modules. Their proposed system enables monitoring of water quality, measurement of consumption, and leak detection in smart homes, providing a monitoring platform and an awareness highlight for both users and administrators.

Andrić et al. [103] proposed a LoRaWAN-based smart water meter system for university buildings. The system identified peak water consumption hours and water leakage. Frequency and time domain analysis revealed usage patterns and leakage rates for each location. The system provides users with real-time data and cost reduction while allowing for more efficient expenditure.

Table 5 provides the answer to Research Question 1 by presenting the various characteristics of the current smart water application design by the researchers for IoT-based smart water applications. It is presented in terms of the type of microcontroller, embedded programming language, deployed sensors, communication module, protocol, and the solutions realized by the researchers. Interestingly, none of the publications employed the 5G mobile network as a communication module for their smart water application development.

5.2. How Are These Studies Geographically Distributed?

Figure 3 shows the distribution of research by country according to the author's location. If a publication had authors from multiple countries, such as an author from the UK and one author from Poland, the statistics included the countries. Figure 2 answers Research Question 2 by demonstrating that most of the reviewed research was conducted by authors in India.

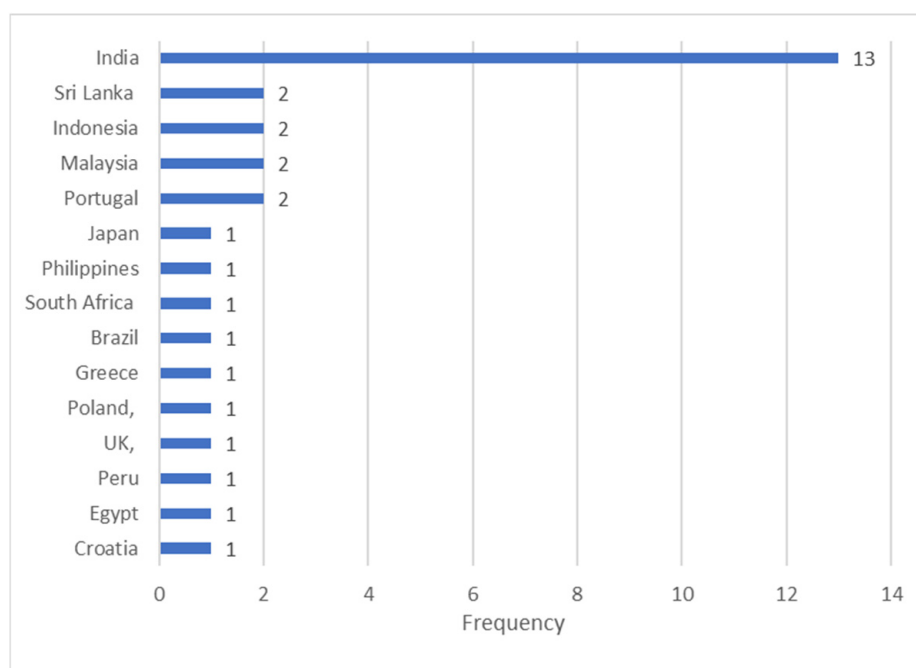


Figure 3. Country of publication determined by the authors' locations.

Figure 4 shows the author's affiliation. The majority of the research was conducted by academia (70%); 12% was conducted from private organizations that specialize in telecommunications and software products; 6% was supported by research institutes; water utility/management and a government agency. Interestingly, three papers were co-written by academia and private organizations, and only one paper was co-written by authors from a water company and research institute, academia and a research institute, academia, and government agency.

Table 5. Characteristics of the current IoT-based smart water application technology in the reviewed publications.

Microcontroller	Embedded Programming Language	Sensors	Communication Module	Protocol	Solution	References
Raspberry Pi, Arduino	X	Turbidity, ultrasonic water level	USB Wi-Fi dongle	HTTP	Water quality monitoring system for a palm oil plantation using solar energy as the main source of energy.	[76]
Wi-Fi gateway	Visual Studio, Microsoft SQL server.	Flow rate, temperature	Wi-Fi router	X	The amount of water consumed by each household appliance is wirelessly recorded, along with the exact consumption time, and stored in a central database. People's water consumption habits may be influenced by real-time water consumption awareness, prompt practical tips for water-saving activities, and individual classification of water consumption behaviour.	[79]
Arduino Uno, Raspberry Pi	Python	Hall Effect flow meter	Wi-Fi build-in	HTTP/WAP	Real-time water consumption data to assist customers in saving water through real-time asset monitoring, water quality monitoring, and water pressure monitoring.	[80]
Electronic Interface Module (EIM)	Android SDK and Java	Build-in tamper flags, tamper signal from Hall effect	Wi-Fi or Bluetooth	WAP	The system reduces the costs for utilities by handling meter readings and billing for water distribution in urban areas.	[81]
NodeMCU	Arduino code (Arduino IDE)	Water flow, flow Rate, Hall Effect	Wi-Fi built-in microcontroller	HTTP	The proposed system calculates the water flow rate, and quantity consumed by householders and sends it to the cloud to monitor water consumption.	[83]
NodeMCU ESP8266, (Raspberry Pi as the home server)	X	Water level	Wi-Fi build-in	MQTT	Monitors water levels and stops water flow in the tank when full.	[82]
Raspberry Pi Zero W model	C Language	Ultrasonic water level, turbidity	Wi-Fi build-in	MQTT	The system allows users to remotely monitor and manage water management systems using their smartphone.	[84]
Intel Edison	Arduino IDE	Water flow	Ubidots	MQTT	Water monitoring and alert system	[85]
MSP 430	Arduino C	Water flow, pressure, solenoid valve	CC2650	MQTT	Detects water leakages, prevents natural water waste, and manages water wastage.	[86]
NodeMCU	LUA	Flow rate	ESP8266—12E	HTTP	Increases individual awareness regarding saving water for sustainable water resources.	[87]

Table 5. Cont.

Microcontroller	Embedded Programming Language	Sensors	Communication Module	Protocol	Solution	References
Raspberry Pi, Arduino Uno	PYTHON, Arduino C	Ultrasonic, turbidity, water flow	Raspberry Pi Wi-Fi build-in	HTTP	The system is designed to distribute the same amount of water to each consumer, maintain the water level in the tank, reduce water wastage, and maintain water quality.	[88]
Arduino UNO	Arduino C	Ultrasonic, flow meter	ESP8266	MQTT	Water wastage is monitored, resulting in a cost-effective system for saving both water and money.	[89]
Arduino UNO	Arduino IDE	Ultrasonic, soil moisture	Arduino Ethernet Shield	HTTP	The system remotely monitors the water level in the tank and soil. Then, it sends alert messages to relevant users' smartphones in the event of excessive water consumption.	[90]
NodeMCU	C language	YF-S201, solenoid valve	ESP8266	MQTT	A detection model for unusual household water use.	[91]
NodeMCU	Arduino IDE	pH, turbidity	ESP8266	MQTT	The SmartOne water bottle is designed to help users drink good quality water and regularly maintain water intake for proper functioning of the human organs.	[92]
Raspberry Pi Zero	MATLAB	YF-S201	Built-in microcontroller	HTTP	The system uses data from household water flow meters that are collected in real time to draw appropriate inferences.	[93]
Node MCU ESP8266	Lua scripting	YF-S201	Wi-Fi built-in MC	MQTT	Uses machine learning to detect excessive water use.	[94]
Node MCU ESP8266	Arduino code (Arduino IDE)	Water flow YF-S201	Wi-Fi build-in	HTTP	Generating water use pattern when implemented, monitoring of urban water resource use pattern, alert system, secure and reliable system, user friendly, proposal of water tariff so people are responsible for their water use, and an architecture that can give room for additional functionalities and computations.	[95]
Arduino Nano, Arduino UNO	Arduino C	YF-S201	Zigbee, LoRa	HTTP	The system detects water theft and water leakages in the pipeline.	[96]
NodeMCU V3 ESP8266	Lua scripting	pH, rainfall, ultrasonic	Wi-Fi build in	MQTP	Collects and retains the quality of precious rainwater in areas with small houses.	[97]
ESP32	Machine learning, Python script, Paho Java MQTT library	YF-B2 Water flow (water rotor and Hall Effect sensor)	Wi-Fi and Bluetooth Low Energy (BLE), LoRa	MQTT (NB-IoT)	The system uses machine learning to monitor water distribution systems, such as irrigation systems, and real-time detection of leaks and their locations in pipes.	[98]

Table 5. Cont.

Microcontroller	Embedded Programming Language	Sensors	Communication Module	Protocol	Solution	References
NodeMCU ESP8266, Raspberry Pi	Python	Water flow, motion sensor	Wi-Fi build-in	MQTT	The system covers five aspects of water consumption: measurement, local record process, security of device, storage and visualization, and leak detection.	[99]
Silab EFM32	X	Tunnel magneto-resistance (TMR) sensor	RF radio for CIU communications, LoRaWAN modem for IoT packet transmissions	HTTP	Smart water meter with a 10-year battery lifespan that is energy-efficient for a municipal setting in Africa.	[100]
NodeMCU ESP8266	Arduino code (Arduino IDE), Kodular IDE	Water flow (Hall Effect flow meter)	Wi-Fi build-in	HTTPS	A smart water meter that sends updates on water flow rate, consumption, and monthly bills via mobile application and SMS service.	[101]
Arduino-based boards	JavaScript and TypeScript	Water flow, ultrasonic	LoRa, Sigfox, NB-IoT, LoRaWAN	MQTT	The system detects water consumption patterns, quantifies water loss, and their location.	[103]
Arduino NodeMCU	C	Flow sensors and water quality sensors (water flow rate, water turbidity, water pH level)	Wi-Fi build-in	X	Leak detection in smart homes, measurement of consumption, and water quality monitoring.	[102]

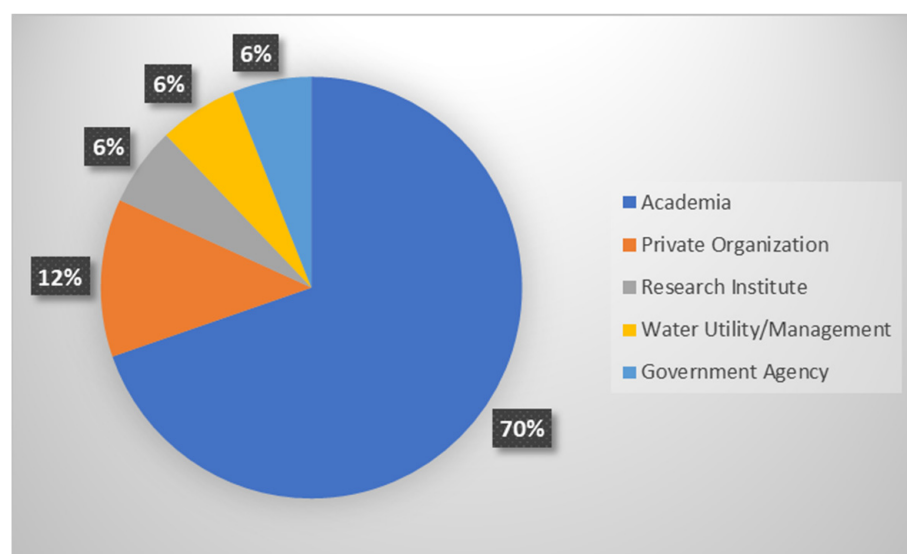


Figure 4. Authors' affiliations.

6. Discussion and Recommendations for Future Research

6.1. IoT-Based Smart Water Technologies

The study review shows various IoT smart water systems that can be used to manage water both in private and public sectors. Water leakages, excessive water use, or water quality can be managed by using this type of system.

Table 5 shows that the researchers used different kinds of microcontrollers such as Arduino Uno, Raspberry Pi Zero W model, Electronic Interface Module, NodeMCU ESP8266, Intel Edison, MSP 430, and Silab EFM32. Various embedded programming languages were used, like Python, C Language, LUA, MATLAB, Arduino C, PHP, JavaScript, and TypeScript. Furthermore, the following are several kinds of sensors used: MPX5700 pressure, temperature, flow rate, water flow, solenoid valve, water level, ultrasonic, turbidity, soil moisture, YF-S201, pH, rainfall, tunnel magneto resistance, and water quality sensors. And the different protocols used were WAP, MQTT, HTTP, and MQTT (NB-IoT). Finally, the researchers used the following communication modules GSM/GPRS, USB Wi-Fi dongle, Wi-Fi router, Wi-Fi build-in, Bluetooth, ESP8266, Raspberry Pi, Arduino Ethernet Shield, Zigbee, LoRa, Sigfox, NB-IoT, and LoRaWAN.

The current literature shows that by integrating LPWAN technologies (e.g., LoRaWAN, Sigfox, LTE-M, and NB-IoT) into the communication architecture of smart water applications, low power consumption, long communication range, and excellent penetration will be achieved. For licensed LPWAN technologies, the literature shows that NB-IoT is preferred due to the vast availability of cellular infrastructure in urban areas. For unlicensed LPWAN technologies, LoRaWAN is one of the most known because it offers enormous opportunities like secure data transmission, which can successfully address the stability and security issues with data transmission. LoRaWAN networks can be used for various smart water applications, including smart water quality monitoring, smart water metering, and leak detection [36].

Findings also showed that some authors used machine learning algorithms to monitor water use, detect water leakages, and abnormal water usage. Machine learning can play an important role in smart water applications. Currently, some machine learning algorithms have been used in smart water management. For more details, consult the relevant literature [62–67].

Interestingly, none of the publications employed the 5G mobile networks as a communication module for their smart water application development. The 5G mobile networks are expected to efficiently support massive devices and new services including machine-type communications (mMTC), enhanced mobile broadband (eMBB), critical communica-

tions, and network operations. For example, the 5G mobile network for the IoT is expected to effectively support basic requirements including high throughput, high scalability to enable many devices, low latency in regards to data delivery, efficient energy consumption method, and ubiquitous connectivity solutions for users [64]. For the future design of IoT smart water applications, it is thus recommended to use a 5G mobile network as we could not identify any smart water application publications in this paper with the 5G mobile network. The 5G mobile network aims to overcome the limitations of previous cellular technologies and could be a key IoT enabler in the future.

A study showed the successful integration of IoT-based smart water applications with three-dimensional (3D) printing. As different sensors are being used to monitor various parameters, 3D printing helps to reduce potential system damage that could be caused by negative environmental influences like dust, wind, and rain [104]. Further, the benefits of 3D printing technology (e.g., fast fabrication, high accuracy, and low cost) have been demonstrated by Wong et al. [76]. Furthermore, the integration of 3D printing with IoT-based smart water technology opens new prospects for low-cost, customization, and fast prototyping of water-related devices and sensors. Continued research into integrating 3D printing technology for water applications could be instrumental as 3D printing reduces negative environmental influences that could potentially damage the system.

Similarly, the integration of photovoltaic solar energy into IoT-based smart water technology is revolutionary because it can increase the sustainability of the system and reduce the reliance on traditional energy sources. A photovoltaic system is a proven and robust technology, with solar modules readily available from a wide range of suppliers. Module lifespan is typically guaranteed for at least 20 years [105], whereas the lifespan of lead-acid batteries is 4–6 years [76]. Future research could focus on designing innovative solar-powered IoT-based smart water technologies and improving their energy efficiency to allow widespread deployment, especially in developing countries such as Nigeria.

In this study, we did not compare the IoT smart water solutions with conventional or standard methods to ascertain their precision. However, it is worth noting that the use of low-cost sensors opens the reach of smart water solutions to areas with limited resources, providing decision makers with real-time insights into water use, water quality, and distribution. Future research should focus on enhancing sensor calibration, accuracy, and durability.

6.2. Publication Distribution by Country Based on Reviewed Studies

The majority of the reviewed studies were conducted in Asia, specifically by authors in India. This finding may indicate a country's priority in water management, availability of funds, academic collaboration, or availability of research infrastructure around smart water application designs. It normally takes a collaborative effort from academia, industry, and governmental bodies to secure national resources such as water.

It will be interesting to see smart water design application publications from Africa as there is presently limited publication from this region. Climate change may have serious implications for water resources in Africa. The United Development Program (UNDP) estimates that by 2080, about 1.8 billion people will suffer from water scarcity, mainly in Africa and other developing nations [106]. Another study predicts that by 2030, water demand will exceed supply by 50% mostly in developing nations [65]. Smart water system applications can help many African countries benefit greatly from ICT, and the water resources available. Extensive and well-documented evidence shows that emerging IoT-based smart water technologies play an important role in water management [21,107]. For future study, academia, industry, and government can use the review's results as a roadmap to identify collaborative opportunities amongst countries with research strengths. Collaborative research initiatives allow for knowledge exchange from different countries, thereby resulting in a more thorough and broad comprehension of complex issues.

6.3. Industry Collaboration

The findings show (Figure 4) that there is a small percentage of publications written by industry. Smart water system designs need a multidisciplinary approach involving water operators, designers/developers/engineers, technology providers, and academics working on cutting-edge technology to ensure that developed smart water applications are widely adopted to help conserve and manage water resources. Future research, especially in developing countries, should explore ways to foster collaboration between stakeholders such as water operators, government agencies, research institutions, private sectors, and academia.

7. Methods Limitation

The following selected databases were used for this study, ACM Digital Library, EBSCOhost, Scopus, and Google Scholar. Some relevant papers may have been missed in other databases. The inclusion and exclusion criteria played a crucial role in the selection processes, helping to identify the papers that were relevant to this study. All necessary precautions were taken during the evaluation of the papers, which was guided by the selected search strings, though it is possible that, with different search strings, additional applicable papers may have been found, and added to the study. The research questions were addressed by analyzing the selected papers, which led to the conclusions. Human error is thus a possibility and must be taken into consideration. Additionally, to ensure that selected papers were timely and relevant to the subject of the investigation, the exclusion criteria disregarded papers not in English and those completed before 2005. Thus, this might have led to the exclusion of some papers from the study's consideration.

8. Conclusions

In this paper, a systematic literature review was conducted to review the current research that leverages the IoT as a communication technology to design smart water applications for water management. It covers statistics on research publications in this area.

Our findings show that various technologies such as microcontrollers, embedded programming languages, sensors, communication modules, and protocols are used by researchers to accomplish their aim of designing IoT-based smart water solutions (see Section 6.1 for a detailed list of technologies used). Interestingly, none of the publications employed the 5G mobile networks as a communication module for their smart water application development. The findings further show that the integration of 3D printing and solar energy into IoT-based smart water applications is revolutionary and can increase the sustainability of the systems.

As a result, the study helps to inform on the current available smart water technologies for managing water resources. It also highlights the integration of innovative technologies. By integrating LPWAN technologies into the communication architecture of smart water applications, low power consumption, long communication range, and excellent penetration will be achieved. Smart water technology is always evolving as such future researchers, system developers, and organizations can leverage on the different IoT components, compare, or integrate systems based on their needs, or perhaps develop more sustainable and efficient applications for water management. Furthermore, realizing the full potential of these innovations for a more resilient and water-secure future will require collaborative efforts from academia, industry, and government. Such collaborative research can enable knowledge exchange and multidisciplinary efforts to design smart water technologies that can be widely adopted for water management.

More funding for research and infrastructure in this area would assist regions with limited publications such as Africa in dealing with rising water demand in areas where water scarcity is expected due to economic development, climate change, and rising population.

Finally, directions for future research are suggested to make sure that developed smart water applications are widely adopted to help conserve and manage water resources. In future work, we would conduct a study, particularly on commercial solutions from leading providers. With the goal of fostering sustainability, resilience, and efficiency in water

management, we hope to provide insightful information to businesses, policymakers, and stakeholders. This would be conducted with the hope that it contributes to the advancement of knowledge in this field.

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