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ORIGINAL PAPER

Framework for the implementation of an Internet of Things (IoT)-based water distribution and management system

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Abstract

This study aims to identify issues plaguing rural India's water supply chain and present a general methodology for the implementation of an IoT-based water distribution and management system in a rural setting. Through the literature review, significant hurdles in the water supply chain of rural India, as well as the potential role of IoT in water supply chain management, were recognized. An implementation plan was proposed to design an IoT-based water distribution and management system with the help of flow meters, ultrasonic sensors, motors, etc. Also, the feasibility of such a system was explored with the help of a use case. This study highlighted that one of the most significant reasons for water scarcity in rural India is the lack of proper infrastructure leading to water resources mismanagement. In the context of our use case, despite adequate availability of physical water for consumption, by the time water is delivered to the consumers, a significant amount of it is wasted due to the lack of an efficient water management system. It was determined that the investment return for the proposed system would break even within three months of installment. This study's results are based on inputs from governmental data collected in the Census report of 2011. As such, the ground level scenario is bound to be comparatively different today. This study is anticipated to guide governmental organizations and policymakers in the formulation of new strategies.

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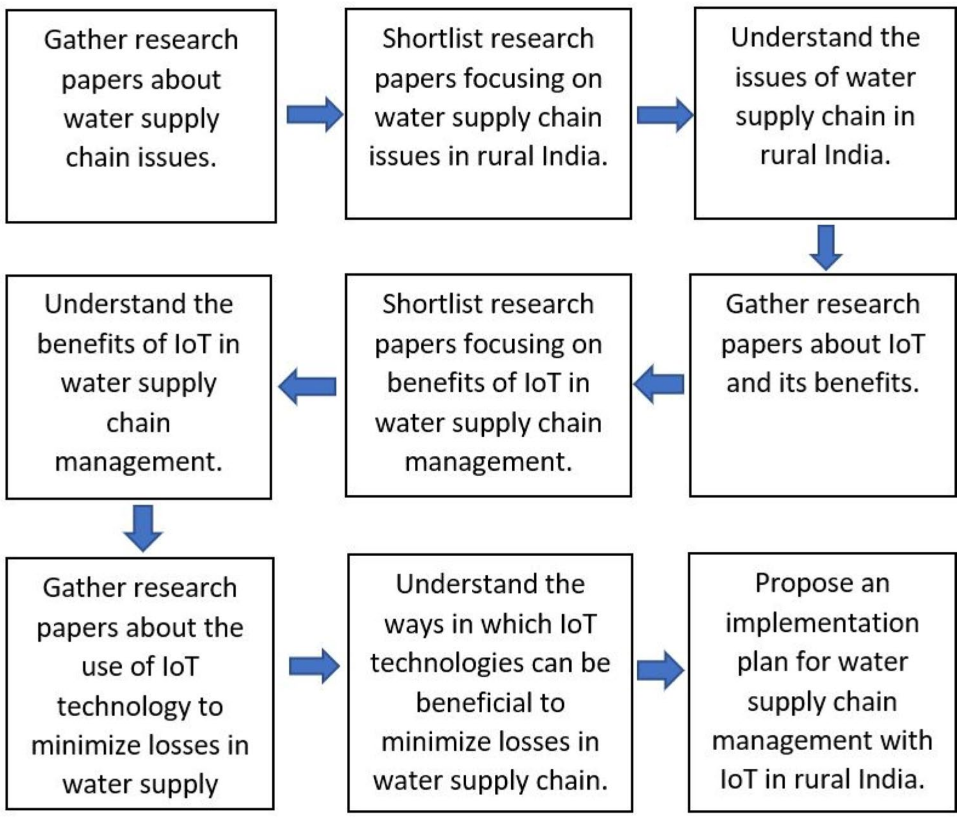
Graphic abstract



Keywords Internet of Things · Water supply chain · Water losses · Water management · Sensors · Return on investment

Abbreviations

Wc	Daily water consumption per capita
P%	Decadal population growth rate
FTwc	Future total water consumption of village per day
IoT	Internet of Things
CMain	Main tank storage capacity
MCM	Million cubic meters
NMain	Number of main tanks
NSub	Number of sub-tanks
P	Population
CSub	Sub-tank storage capacity
CTotal	Total storage capacity
Twc	Total water consumption of village per day
YTotal	Total yield of dug wells and borewells per day

Introduction

The conjunction of developments in various technologies like microelectromechanical systems (MEMSes), wireless communication technologies, and the internet has culminated in the idea of the Internet of Things (IoT). In the year 1999, Kevin Ashton described the concept of a network of interconnected "things" with the term "Internet of Things" (Ashton 2009). With the number of devices connected to the internet estimated to cross 75 billion by 2025, IoT has the potential to become a ubiquitous global computing network where everyone and everything would be connected (Alam 2018). Having all these devices communicating with each other by wire or wireless technologies will put a substantial source of information at our fingertips (Aros et al. 2019). The general concept of IoT is to allow the exchange of useful information collected by sensors, which is then analyzed for decision making, based on which actions are performed in real-world applications (Farooq et al. 2015). Thus, over the years, IoT has evolved from its preliminary supply chain management to include wide-ranging applications like utilities, healthcare, and transport (Geetha and Gouthami 2016; Huck et al. 2017).

The implementation of IoT for water supply chain management can help tackle one of the most critical challenges of inefficient water management: a lack of adequate scientific data about water resources (Rijsberman 2006). With the help of interconnected sensors that collect real-time information about their environment and communicate with each other, IoT can prove to be a promising solution. Jain et al. (2020) designed an affordable IoT-based water quality monitoring system utilizing various sensors like Fluoride sensor and Electrical conductivity sensor to calculate the water parameters. Information regarding such parameters could be collected and processed with cloud computing (Fuentes and Mauricio 2020). Analysis of such data would aid in better management of water.

Moreover, the application of IoT technology can prove valuable in water distribution efforts and the detection and prevention of leakages in the water supply chain (Arshad et al. 2020; Lee et al. 2018). Wastewater management is also a domain in which the employment of IoT technologies can be viable (Peng et al. 2015). Thus, it can be said that the use of IoT technologies throughout water supply chain management will ensure better water collection, storage, distribution as well as treatment (Zeng et al. 2020; Brandi and Dos Santos 2016). In this study, we have studied various case studies of IoT applications for efficient water management. We have also proposed a methodology for implementing an IoT system for efficient water management in a rural setting in India.

In the literature section, many studies have focused on the application of IoT in the context of water management (Gubbi et al. 2013; Ismail et al. 2019; Nie et al. 2020; Odiagbe et al. 2019; Morais et al. 2019). This study aims to present a methodology for the implementation of water distribution and management systems and explore the feasibility of adopting IoT technology for water supply chain management in a rural setting with the help of a use case. This research is intended to help policymakers envision strategies for implementing IoT-based water management and distribution system in parts of rural India facing water scarcity.

To propose a methodology for implementing a water distribution and management system in rural India, a thorough understanding of the various issues plaguing the existing water supply chain must be studied. Consequently, the various applications of IoT in the domain of water supply chain management, the challenges, and opportunities that may arise with the adoption of IoT technology must be explored. Once a firm grasp regarding these factors has been acquired, the IoT technologies that would be crucial in minimizing the existing water supply chain losses need to be identified. After that, an implementation plan for water distribution and management system can be proposed. As such, this study seeks to address three key research questions in the context of IoT in the domain of water supply chain management in rural India. The research questions (RQs) are as follows:

RQ1 What are the issues of the water supply chain in rural India?

RQ2 How can IoT be beneficial in water supply chain management?

RQ3 Which IoT technologies will be beneficial to minimize losses in the water supply chain?

Addressing these research questions would enable one to achieve a thorough understanding of opportunities and hurdles of implementing IoT technologies in the domain of water supply chain management in rural India. Various research papers and surveys were collected, shortlisted, and studied to address these research questions, based on which a methodology was proposed. Initially, these research questions were framed based on the SSCs and the buyer–supplier relationship during COVID-19. This was followed by selecting databases, including "Scopus" and "Web of Science" (WoS). Formulation of keywords like "Sustainable Supply Chain" AND "Supply chain," AND "Resilient" OR "Supplier relationship" OR "Supplier network" to be searched was carried out. The presence of these keywords in the titles, keywords, and abstract of the research papers was considered essential. The type of the document considered in the research was 'articles' and the time limit for our research was decided to be from "2010 to 2020." The first search resulted in 454 articles in WoS and 934 articles in Scopus. After the omission of duplicates from the databases, 1045 articles were selected related to the research questions. Only the articles appeared in journals are undertaken; therefore, conference papers, proceedings, and working papers were excluded. After excluding the unrelated articles, 189 articles were chosen. After reading the abstracts of the shortlisted papers, 42 papers are finally selected. From the selected papers, factors for enhancing the survivability of SCs and buyer–supplier relationships were identified.

The remainder of the study is structured as follows. "Literature survey" section consists of the literature review. "Proposed methodology" section describes the proposed methodology for this study. "Case Implementation" section features the case implementation. "Discussions" section consists of discussions, whereas "Conclusion" section gives the conclusion of the study.

Literature survey

The constraints faced by each country differs vastly depending on various factors like infrastructure, economic backing, technological capabilities, resource availability, political will, and population. This section is classified into two subsections: studies written by industrialized economies and studies written by developing economies.

The tables below summarize the papers published in the domain of IoT in water supply chain management. It details that research work in the field of IoT in water supply chain management has been carried out in industrialized economies like Australia, China, and the USA, as well as in developing economies like India, Pakistan, and Brazil. It shows that many countries worldwide are interested in adopting IoT for the discipline of water supply chain management.

Studies from industrialized economies

Gubbi et al. (2013) discussed in their research current trends in IoT applications and advocated the need for convergence of multiple interdisciplinary technologies. With the help of Aneka, a cloud application founded on the interaction of private and public clouds, they presented a cloud-centric vision for the global implementation of the IoT. Lloret et al. (2016) proposed an integrated IoT architecture with smart meter networks for electricity, water, and gas smart metering, to be installed in smart cities. They advocated using big data analysis to make decisions and present relevant information to utilities and customers. Wong and Kerkez (2016), with the help of a use case in the discipline of hydrology, estimated that the installation of an adaptive sampling algorithm effectively enhances the usage of a typical resource-constrained sensor network. They concluded that by leveraging recent advances in the IoT arena and real-time data, environmental sciences would benefit significantly.

Kang et al. (2017) proposed a localization algorithm that is graph-based to deduce leakage location in a water distribution system. It was concluded that by comparing actual measured signals with virtually generated signals, leakage locations at which costs are minimized could be estimated faster than conventional methods. Ismail et al. (2019) reviewed various detection methods of leakage in water pipelines and characterized them. They also presented a comparative study of vibrational sensors, having various parameters like cost and precision in detecting leakages in pipelines. It was concluded that ADXL335 sensor has higher accuracy in identifying leakages. Maamar et al. (2019) discussed the design and development of Cognitive Things and illustrated them with a water leak case study. They proposed weaving cognitive abilities like reasoning, learning, and adaptive capabilities into "things" for specific service applications. It was highlighted that the proposed system was able to execute repeated leakage incidents faster than executing new incidents. Nie et al. (2020) suggest Supervisory control and data acquisition (SCADA) approach for feasible water management in a smart city employing IoT and Big Data Analytics. With the help of experimental results, it was established that the consumption of water by corporations and individuals could be regulated to construct a more sustainable water supply chain.

The above studies are tabulated as below (Table 1)

Studies from developing economies

Cloete et al. (2016) designed a water quality monitoring system intended to alert consumers of instantaneous water quality parameters. With the help of an experimental study, it was concluded that the proposed system could display real-time water quality parameters to consumers and alert them if they dropped below certain desired levels. Farooq et al. (2015) reviewed the literature and described a multilayered architecture of IoT. The various fields in which IoT could be applicable and associated key challenges were highlighted. Pandey and Sharma (2016) employed a community-based natural resource management approach to tackle water scarcity in Maharashtra villages. They experimented with the likelihood of implementing the de-siltation of tanks and rivers, thereby increasing their water carrying capacity. Results showed that such a community-based natural resource management approach successfully rejuvenated the rivers involved.

Adedeji et al. (2017) discussed in their research prevailing leakage detection methods, localization techniques, challenges, and research advancements in this domain. It highlighted that while existing techniques can detect burst type leakages to some extent, in a large-scale piping network, background type leakages are often hidden and difficult to detect by existing techniques. Daadoo and Daraghmi (2017) emphasized the need to implement wireless sensor networks to detect leakages in underground water pipes. The experimental study results concluded that using Smart Water Leakage Detection (SWLD) in water supply pipelines helps quantify water level in a storage tank and regulate motor pumps and actuate it when the water level is below a limit. Geetha and Gouthami (2016) proposed a relatively cheap, straightforward water quality monitoring system that was modeled to examine water samples and transmit essential data to the cloud to be analyzed. The results highlighted that their experimental setup was able to alert the consumer when water quality parameters deviated from predefined levels and the results of data collected in the cloud could also be displayed with the help of a dashboard.

Parameswari and Moses (2017) highlighted the need for an IoT-based water quality monitoring system instead of conventional systems. They developed a low-cost, IoT-based water quality monitoring system to provide reliable water quality information to the community. Simulations of the proposed setup validated increased efficiency of the system at low computational cost and lesser execution time. Shivpuje et al. (2017) analyzed water shortage in the upper Manar sub-basin of the Deccan trap, part of Marathwada. They conducted a case study that highlights that lack of water management is the main reason for water shortage in the Marathwada region. Saravanan et al. (2018) proposed a novel SCADA system that combines with IoT technology for monitoring water quality in real time. Experimental results show that the proposed system, with the help of Arduino Atmega 368 and the Global System for Mobile Communication (GSM) module, outperforms conventional water quality monitoring systems and produces more accurate results.

El-Zahab and Zayed (2019) reviewed the literature and stated that to outline leak detection stages, a unique approach, i.e., the identify-localize-pinpoint approach, was required. They concluded by identifying two types of leakage detection techniques: static leakage detection technique, dynamic leakage detection technique, and an overview of general leakage detection mechanisms. Kawarkhe and Agrawal (2019) proposed a system with smart sensors to combine water pipeline leakage monitoring, water pollution monitoring, and water tank level monitoring. The results show that the proposed system can be used to alert the consumer and is more economical, convenient, and faster than traditional systems. Morais et al. (2019) reviewed the literature and identified 15 applications of IoT to help developers and data analysts to comprehend the features of an IoT application better. They also proposed a method to categorize and compare IoT contexts. It concluded that the smart home is the most common application of IoT. Odiagbe et al. (2019) proposed a detailed framework for a water quality monitoring and management system. Experimental results concluded that the simulated tests and data analysis enabled remote monitoring and controlling of detected leakages.

The above studies are tabulated as below (Table 1):

While research effort into the applications of IoT in the water supply chain has increased significantly in the recent years, several research gaps in the prevalent literature regarding IoT applications in the water supply chain have been observed. Most of the research focus in the current literature seems to be concentrated on water quality management's IoT application. Research effort into the implementation of an IoT-based water management and distribution system has been limited to Home applications or Smart city applications. Research studies regarding the implementation of an IoT-based water management and distribution system in the rural context have hardly been conducted. The lack of proper infrastructure, lack of investment, etc. leads to significant losses along the water supply chain in rural settings. As such, this study aims to propose a methodology to design an implementation plan for an IoT-based water management and distribution system in the context of rural India.

Proposed methodology

By considering the research objectives, a methodology has been proposed. This methodology summarizes the procedure to be followed to design an implementation plan for the adoption of IoT technology for water supply chain management in rural India.

The proposed methodology consists of nine steps, which are explained below, and a flowchart of the same is given in Fig. 1.

The first three steps in the proposed methodology aim to achieve our first research objective. By gathering research papers and shortlisting them by focusing on water supply chain issues in rural India, a thorough understanding of existing problems in the water supply chain can be gained. The second research objective can be realized by following steps four to six in the proposed methodology. By studying IoT and its benefits and shortlisting papers that focus on the benefits of IoT in water supply chain management, comprehensive knowledge about IoT and its implementation in the water supply chain can be achieved. Steps seven to nine help realize the final research objective of this study. Specifically collecting research papers about the use of IoT technology to minimize the losses in the water supply chain, and studying them, helps identify IoT technologies required to minimize the losses in the water supply chain and ensure efficient water management. It is thereby enabling the design of a detailed implementation plan for water supply chain management with IoT in India's rural setting.

The proposed methodology was designed based on the identified research questions. Thus, its main aim was to propose an implementation plan for the adoption of IoT technology for water supply chain management in the context of rural India. As the issues afflicting the water supply chain of other countries are bound to be different, the proposed methodology would need to be modified accordingly. The proposed methodology concentrates mainly on minimizing the losses in the existing water supply chain. Research studies into the applications of IoT for wastewater management, water quality analysis, smart irrigation, etc. have not been explored extensively. While research into IoT is being conducted globally, only those published in the English language have been considered in our proposed methodology.

Case Implementation

In this section, the implementation plan for the adoption of IoT technology for water supply chain management in rural India based on the proposed methodology is explored. The individual steps identified in the proposed implementation plan are as follows:

- Step 1 Identification of the village
- Step 2 Collection of data through field surveys
- Step 3 Prototype development
- Step 4 Propose Bill of Material

Identification of village

The village of Chilka, in Ahmadpur Tahsil of Latur district of Maharashtra, was identified based on its population, agricultural area, water availability, and scarcity, as the focus of this study. Chilka is a medium-sized village having an area of 571 hectares in the southern part of Maharashtra, which lies along 18°44′ 18.0″ N 76°53′ 33.9″ E. Chilka has a total of 203 families residing in it, with a population of 875 (Census of India 2011).

The villagers' main occupation is agriculture-related, be it cultivators, cattle rearing, or agricultural laborers. The climate in the entire district of Latur is dry throughout the year. Therefore, the residents of Chilka must mostly depend upon the groundwater resources available to them through dug wells or borewells for their agricultural and domestic purposes. A satellite view of Chilka is shown in Fig. 2. It can be seen from Fig. 2 that the village of Chilka has nine dug wells and four borewells for their groundwater needs.

Collection of data

Due to the prevalent pandemic conditions, data collection through field surveys was impractical. As such, all the data collected in this study is through official reports published by various departments under the Government of India, viz. Directorate of Census Operations, Groundwater Surveys and Development Agency, Central Ground Water Board, Ministry of Water Resources, etc. In India, Census reports are a decadal practice, as such, in-depth information about the current water crisis scenario in the rural context would be unavailable till 2021. Thus, information regarding the availability of water resources, demand for water, based on agricultural as well as domestic demand, and water scarcity index was studied. The conclusions drawn from the insights provided by these reports have been discussed below.

Daily water consumption per person in the Ahmadpur Tahsil rural areas, like Chilka, is about 60 L (Poul 2014). According to the Falkenmark indicator, water availability per person should be at least 1700 m^3 yearly. Poul (2014) explains that even though the amount of physical water available in Ahmadpur Tahsil is over the Falkenmark indicator, delivered water availability per capita is far lower than the 1700 m^3 mark. This means that there is significant mismanagement of water, which leads to a severe water crisis. As such, there is a need for an efficient water management and distribution system. The total water consumption of the entire village of Chilka per day can be calculated as follows,

$$T_{wc} = P * W_c \tag{1}$$

Thus, daily water consumption for the village of Chilka is calculated by Eq. (1) to be, $T_{wc} = 52{,}500$ L.

According to the Census of India (2011), decadal percentage growth in Ahmadpur Tahsil is 19.92%. Assuming that a water management and distribution system would last 20 years with minimal maintenance, the system's total storage capacity must be designed by taking into consideration population growth over the years. As such, total water consumption of the village Chilka per day, 20 years in the future can be calculated by

$$FT_{wc} = (P + (P * 2 * P\%)) * W_c \tag{2}$$

Therefore, future total water consumption of the village per day is calculated by Eq. (2) to be, $FT_{wc} = 73{,}416$ L.

According to the report on Ground Water Information Latur district (2013), the yield of dug wells in Latur ranges between 25 and 250 m^3/day, whereas the yield of borewells in Latur varies from 0.50 to 52.00 m^3/day. For this study's purpose, the average yield of dug wells for the village of Chilka is assumed to be 80 m^3/day, whereas the average yield of the borewells is assumed to be 10 m^3/day. Therefore, the total yield of dug wells and borewells per day for the village of Chilka is 90 m^3/day. Thus, YTotal = 90,000 L/day.

In the case of Chilka, physical water is available, and as such, water scarcity is mainly a result of the lack of proper water management and distribution system. While designing such a system, the expected life of the system and the future water demand of the village need to be considered. Thus, the system is designed to have a total storage capacity of 80,000 L. To cover the entire geographical area of the village, while also keeping expenditures to a minimum, total storage capacity is met with the help of main tanks having a water storage capacity of 10,000 L and sub-tanks having a capacity of 5000 L. The total capacity of the system and the number of tanks required can be given by,

$$\text{CTotal} = (\text{CMain} * \text{NMain}) + (\text{CSub} * \text{NSub}) \tag{3}$$

Thus, the total storage capacity of the proposed water management and distribution system is calculated by Eq. (3) to be, CTotal = 80,000 L.

Prototype development

Water management and distribution system require motor pumps, water storage tankers, IoT devices like flow meters, pressure sensors, ultrasonic water level sensors, solid-state relays, and electronic valves. For the prototype stage, single-phase motor pumps, with 1HP, would be required to pump water from a borewell and pumping water from the main tank to sub-tanks. For the prototype, least two such motors would be required, one to pump water from the borewell to the main tank, and the other to pump water to individual sub-tanks. The price of one such motor comes to roughly Rs. 5000, and overall expenditure for motors in the prototype stage would amount to about Rs. 10,000. Figure 3 displays the general outline for enabling a water management and distribution system.

A pressure sensor with an operating pressure ranging from 0 to 10 bars, requiring a supply voltage of 30 V to operate, would be ideal. The cost of one such pressure sensor is about Rs. 9500 roughly. Once water is pumped from the borewell with a single-phase motor pump, it needs to be stored in the main tank. For the prototype stage, a Sintex triple-layer upper groundwater tank, with a storage capacity of 5000 L, could be selected as the main tank. The price of one such tanker is about Rs. 37,500. Flowmeters would have to be placed between the water distribution network to measure the flow rate of water between tanks to detect any leakages. Flowmeters with a minimum flow of 0.45 m^3/h and a maximum flow of 30 m^3/h would be ideal for measuring the rate at which water would be flowing in the distribution network. For the prototype, three flowmeters would be required to measure the water's flow rate in the water distribution system. The cost of one such flow meter is about Rs. 9500. Therefore, the expenditure on flowmeters for the prototype stage would be about Rs. 28,500.

Water pumped into the main tank would have to be stored in sub-tanks, for which, two Sintex triple-layer upper groundwater tanks with a storage capacity of 2000 L each, could be selected. The price of such a tank is Rs. 15,000, and as such, for the prototype stage, this would come out to be about Rs. 30,000. Ultrasonic rangefinders/water sensors having a 40 kHz frequency and a range of 6 m, needing a supply voltage of 12 to 24 VDC, would be ideal for detecting water level in tanks. These are priced at around Rs. 7000 per piece, and thus, for the prototype system, expenditure on ultrasonic rangefinders would be about Rs. 21,000, as we would require three of such sensors.

With the help of electronic valves and solid-state relays, an actuation system could be created to enable automated management and distribution of water throughout the network. The number of devices required for the actuation system is dependent on the number of tanks and sub-tanks. The real-time information from sensors would be communicated to a central system with IoT networks, which could be used to monitor the entire water management and distribution system. Raspberry Pi is a small computer, which can be used as a platform for IoT applications such as a water management system. A Raspberry Pi costs about Rs. 3500. Electronic valves and solid-state relays vary depending on various parameters; however, they are comparatively cheaper. An electronic valve could cost anywhere between Rs. 70/piece to Rs. 5600/piece. Whereas solid-state relays usually cost around Rs. 500/piece to Rs. 2000/piece. By ensuring that these devices work following each other, efficient water management and distribution prototype systems can be created. It would pump water from the borewell, store in the main tank, and distribute it to sub-tanks, as and when required. The overall expenditure for the IoT devices in the prototype stage would roughly be about Rs. 77,000.

Bill of materials

The bill of materials for implementing the proposed system was estimated based on the village's calculated daily water consumption, the number of borewells and dug wells in the village, and the average cost of the required devices. The table below displays the estimated bill of materials for implementing the proposed water management and distribution system in Chilka, from Ahmadpur tahsil, in Latur district of Maharashtra.

According to extrapolated data from Poul (2014), the water scarcity experienced by the village of Chilka is mainly due to humanmade reasons, with 60.89% of developed water being lost by the time it is delivered to the consumers. Consequently, this has led to a rampant dependency on private water tankers for their daily needs. A water tanker having a capacity of 6000 L costs anywhere between Rs. 800 and 1200, which works out to Rs. 6 per liter approximately (Chatterjee 2016). According to the calculated water demand, the proposed system can provide roughly 90 L of water daily per capita for domestic purposes. Whereas, to achieve similar results with water tankers' help, every citizen of Chilka would have to spend approximately Rs. 65,700 annually. Therefore, the return of investment for the proposed system will break even within three months of installment. On-demand access to water will drastically reduce the man-hours previously spent on the collection of water, thereby enabling better utilization of their time.

The bill of materials for the proposed water management and distribution system provides a broad understanding of the feasibility of implementing such a system in India's rural setting. By implementing the proposed system, significant losses along the entire water supply chain of rural India can be avoided. Consequently, providing access to water for each citizen of Chilka daily would be achievable. After implementation, the proposed system could be further modified to tackle the remaining losses in the water distribution channel efficiently.

Discussions

Water is an essential resource for the sustenance of all life on Earth. Although about 70% of the Earth's surface is covered by water, only 3% of it is freshwater, and the rest is saline and ocean-based (Boudreau et al. 2011). Nevertheless, just about 1% of freshwater is suitable and readily accessible to

Table 1 Research studies from industrialized economies

Sr. no.	Publications	Country	Tools and techniques used	Type of paper
1	Gubbi et al. (2013)	Australia	IoT, Cloud computing, Ubiquitous sensing, RFID, Smart environments, Wireless sensor networks	Literature review
2	Lloret et al. (2016)	Spain	Smart metering, Network architecture, IoT, Big Data	Case study implementation
3	Wong and Kerkez (2016)	USA	Sensor networks, On-demand web services, IoT, Adaptive sampling	Case study implementation
4	Kang et al. (2017)	South Korea	Neural networks, Support vector machines, Graph-based localization algorithm, Leakage detection methods	Case study implementation
5	Ismail et al. (2019)	Malaysia	IoT, Leakage detection techniques, Sensors	Theoretical study
6	Maamar et al. (2019)	United Arab Emirates	Cognitive computing; IoT; Sensors	Case Study Implementation
7	Nie et al. (2020)	China	Water management systems, Big Data Analytics, Wireless sensor networks, IoT, Sensors	Case study implementation

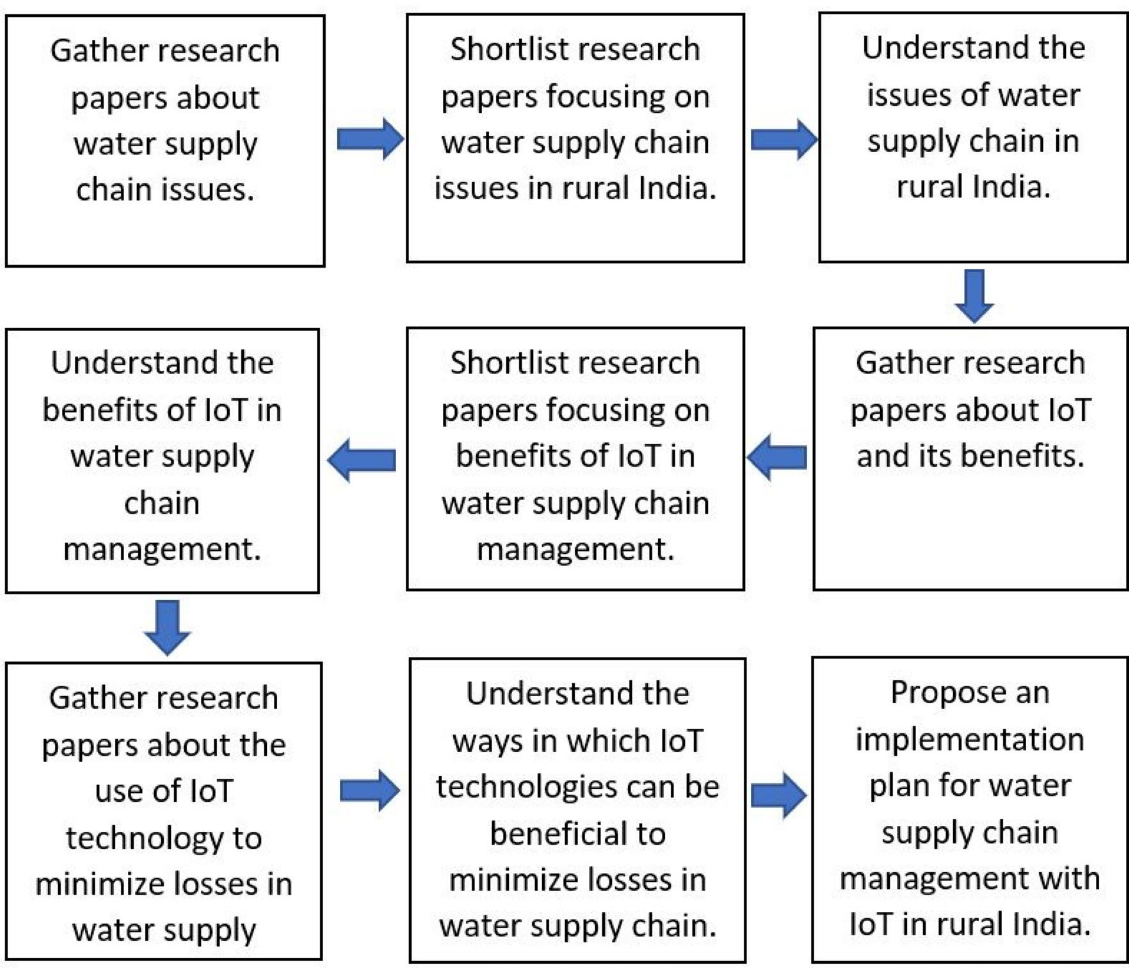


Fig. 1 Proposed methodology. *Source* Author

humans, as most of it is trapped in glaciers and snowfields. As a result, water is a limited resource. With freshwater depleting at an alarming rate, studies predict that more than 40% of the global population will be facing severe water scarcity by 2050 (Connor and Koncagül 2014). With the ever-increasing population, expansion in agricultural and industrial activities, changing climate scenarios, water supply management has become increasingly challenging.

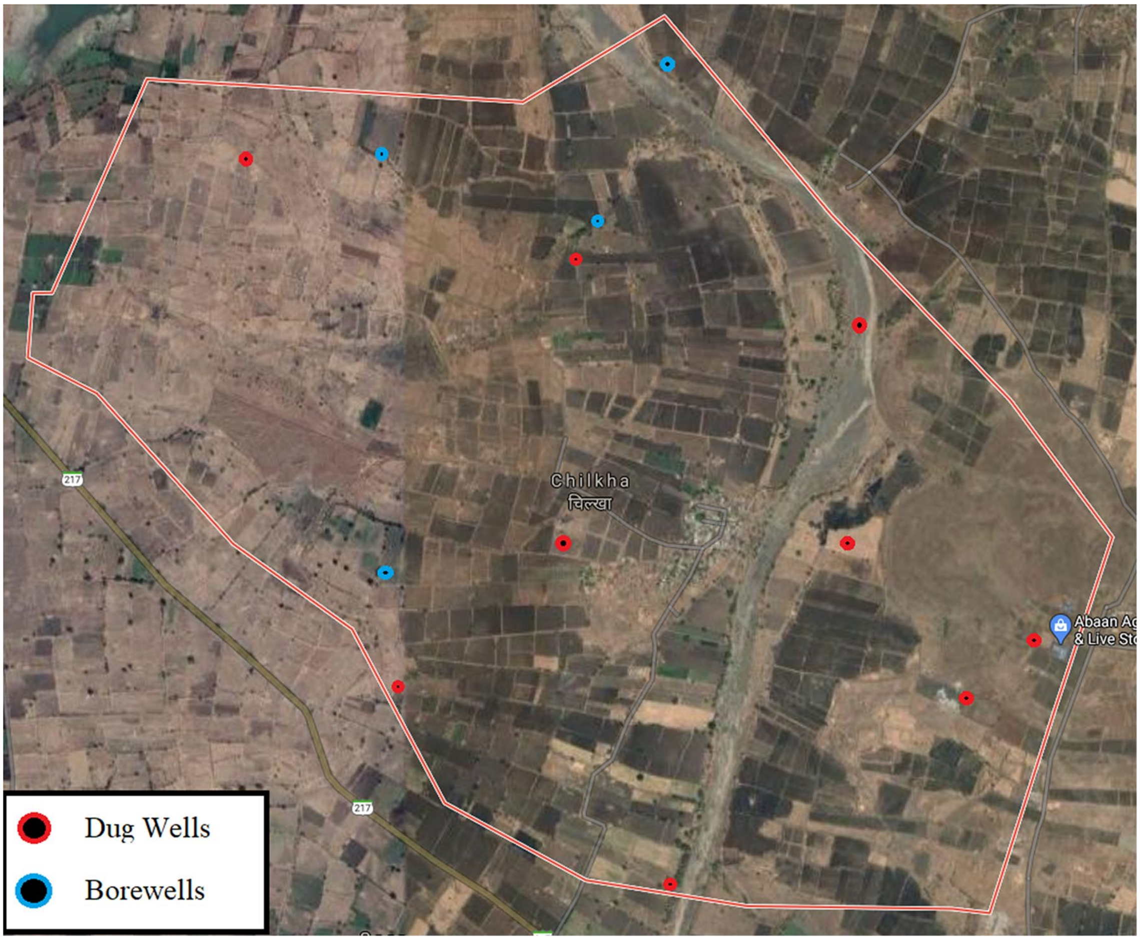


Fig. 2 Satellite view of Chilka. *Source* Author

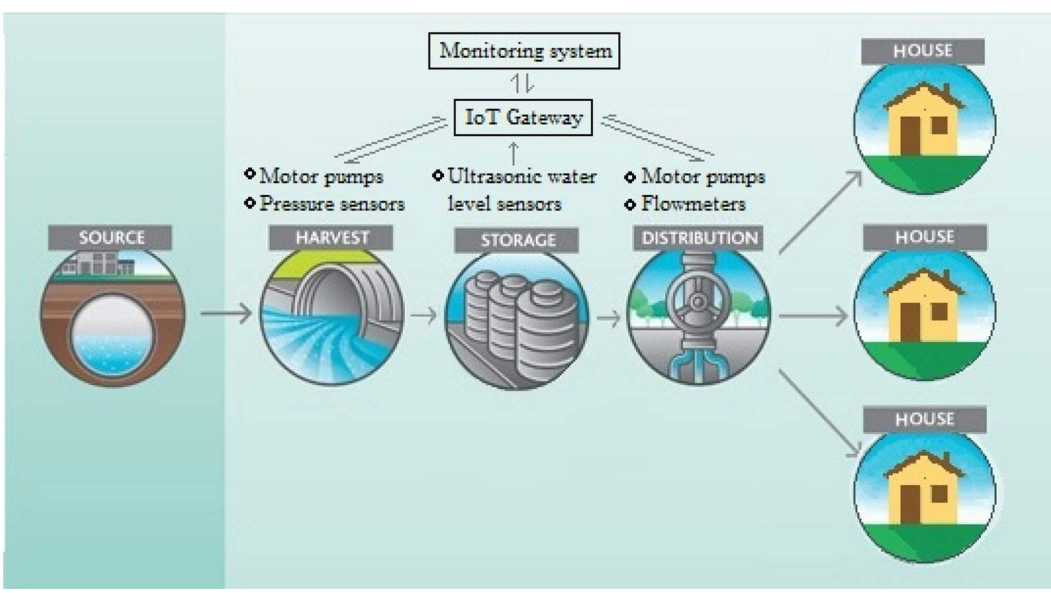


Fig. 3 General outline of water management and distribution system. *Source* Author

One of the most significant challenges that various economies face today is water availability and accessibility (Voss et al. 2013). In this regard, efficient water management has become the need of the hour. Water supply chain management can be defined as the wide-ranging tasks needed to plan, regulate, and implement the flow of water, from procurement to distribution, in the most efficient way to answer the needs of the people (Rouse et al. 2019). Reliable information regarding the supply and demand of water resources is essential for efficient water management. Some of the key challenges for water supply chain management are collecting, managing, and analyzing information about various parameters like the quality of water, environmental data, etc. Recent technological advancements can prove helpful in tackling these challenges. In the present study, a review of the research studies in the literature section shows that while both industrialized and developing economies have been focusing on the application of IoT in the water supply chain domain, their approaches have varied based on their respective constraints (Tables 1, 2).

The availability of proper infrastructure, technological competencies, and financial backing enables industrialized economies to focus on improving efficiency and the overall capabilities of their existing water supply chain systems. The widespread application of novel technologies like Cloud Computing, Big Data Analytics, Convolutional Neural Networks, Cognitive Computing, and SCADA, in conjunction with IoT technologies, is highlighted in the research papers from industrialized economies (Lloret et al. 2016; Wong and Kerkez 2016; Kang et al. 2017; Maamar et al. 2019; Nie et al. 2020). The scope of the case study implementation papers from industrialized economies is focused on improved leakage detection in the piping network (Kang et al. 2017; Maamar et al. 2019), water quality monitoring (Wong and Kerkez 2016; Nie et al. 2020), and metering the resource consumption of companies and individual consumers (Lloret et al. 2016).

Developing economies like Brazil, India, Pakistan, and others lack proper infrastructure, financial, and technological capabilities compared to industrialized economies. Additionally, their enormous population places a significant amount of stress on their existing supply chains. As a result, the research papers from developing economies tend to rely heavily on cost-efficient novel technologies like Cloud Computing and SCADA, in conjunction with IoT technologies (Geetha and Gouthami 2016; Parameswari and Moses 2017; Saravanan et al. 2018; Odiagbe et al. 2019). In the case of developing economies, the scope of the case study implementation papers is concentrated mainly on water quality monitoring (Cloete et al. 2016; Geetha and Gouthami 2016; Parameswari and Moses 2017; Saravanan et al. 2018; Kawarkhe and Agrawal 2019), leakage detection (Daadoo

Table 2 Research studies from developing economies

Sr. no.	Publications	Country	Tools and techniques used	Type of paper
1	Cloete et al. (2016)	South Africa	Water quality monitoring, conductivity sensor, ORP sensor, flow sensor, temperature sensor, ZigBee, pH sensor, Wireless Sensor Networks	Case study implementation
2	Farooq et al. (2015)	Pakistan	IoT, WSN, RFID,	Theoretical study
3	Pandey and Sharma (2016)	India	Community-based natural resource management (CBNRM), Water Resource Management, Water Shortage Issue	Case study implementation
4	Adedeji et al. (2017)	South Africa	Leakage detection, water distribution network, wireless sensor network	Theoretical study
5	Daadoo and Daraghmi (2017)	Palestine	Arduino, GSM Module, Leakage detection system, WSN	Case study implementation
6	Geetha and Gouthami (2016)	India	IoT, Wi-Fi, Cloud storage, Sensor networks	Case study implementation
7	Parameswari and Moses (2017)	India	IoT, Wireless Sensor Networks (WSN), Arduino Uno, GPRS	Case study implementation
8	Shivpuje et al. (2017)	India	Water Resource Management, Water Shortage Issue	Case study implementation
9	Saravanan et al. (2018)	India	Sensors, GSM module, IoT, Leakage detection, Arduino Atmega 368, SCADA, Real-time water quality monitoring system	Case study implementation
10	El-Zahab and Zayed (2019)	Lebanon	Leak detection technologies, IoT, Web of Knowledge (WoK)	Theoretical study
11	Kawarkhe and Agrawal (2019)	India	Temperature Sensor, pH Sensors, Ultrasonic Sensor, Flow Sensor, Microcontroller	Case study implementation
12	Morais et al. (2019)	Brazil	IoT, Data analysis, Survey, Sensors	Literature review
13	Odiagbe et al. (2019)	Nigeria	IoT, Solenoid valves, Water Management System, Sensors, Cloud computer	Case study implementation

and Daraghmi 2017), and water management (Odiagbe et al. 2019).

As the water management and distribution system's total water storage capacity had to be sufficient to sustain the water demands of the current and the future population of the village of Chilka, the overall number of items had to be scaled up. The number of tankers required to design such a system was calculated based on data recovered from the research phase. Accordingly, a total of four tankers of 10,000 L storage capacity and eight tankers of 5000 L storage capacity were selected for the implementation of the proposed system. The number of IoT devices to be used was extrapolated based on the number of tankers required. The total estimated expenditure for implementing this proposed system for the village of Chilka is thus calculated and shown in Table 3.

Implications of the study

Populous countries like India must reduce losses in their water supply chain to satisfy their consumption requirements. This paper motivates developing economies like India to take initiatives to implement an IoT-based water supply chain with the help of a use case. This study is beneficial to governing bodies and policymakers to address losses in the existing water supply chain. Focusing on all the criteria involved in the supply chain is difficult. As such, this study helps governing bodies create policies/strategies by providing them the means to access real-time information about the water supply chain with the help of IoT technology. As a result, this study can be helpful to policymakers for the evaluation of new and existing policies.

This study concentrates on designing and developing a framework for the implementation of a water management and distribution system in a rural setting in the Indian context. As such, this study's focus was to verify the feasibility of a water management and distribution system in the rural context. Since this study shows that the proposed system would be feasible, research effort could direct the implementation of the proposed system on a prototype level for further validation. Additionally, the proposed system could be modified to ensure autonomous water quality management with additional sensors, data analytics, etc.

Conclusion

In this study, novel technological advancements in IoT and its implementation in water supply chain management have been explored. Firstly, recent studies in the domain of IoT and its application in water supply chain management, as well as the issues plaguing the water supply chain of rural India, have been studied. Secondly, a methodology has been proposed to implement IoT technologies in a rural setting in India. Accordingly, a village has been identified, and its water demand and availability of water resources have been studied. Consequently, a water management and distribution system has been put forth, which would sustain the village's domestic water demand for about 20 years. An approximate bill of materials has been calculated based on the number of devices required for the proposed system. It was determined that the investment return for the proposed system would break even within three months of installment. In the future, this system could be modified to monitor the quality of water.

This paper's results are based on inputs from the governmental data collected in the Census report of 2011. As such, the ground-level scenario is bound to be comparatively different today. As this study has been conducted in the Indian context, appropriate modifications are needed to apply it to other developing economies. The focus of the designed implementation plan for an IoT-based water management system is limited to efficient distribution and water management for a rural setting in India. As such, it lacks a water quality monitoring system. The proposed system focuses on efficient procurement, storage, and distribution of water and leakage detection to avoid losses in the water supply chain. Future studies could enhance this

Table 3 Bill of materials

Sr. no	Item	Price per part (Rs.)	Quantity	Total (Rs.)
1	Water tanker (10,000 L)	80,500	4	3,22,000
2	Water tanker (5000 L)	37,500	8	3,00,000
3	Pressure sensors	9500	12	1,14,000
4	Flowmeter	9500	12	1,14,000
5	Ultrasonic water level sensor	7000	12	84,000
6	Motor pumps	5000	25	1,25,000
7	Solid-state relays	500	12	6000
8	Electronic valves	500	12	6000
9	Miscellaneous			5000
	Total expenditure			10,76,000

system by installing sensors that could be used to monitor water quality parameters like pH level, turbidity, conductivity, etc. Agriculture is the most prominent source of occupation in rural India. As agriculture activities are heavily dependent on water availability, future research effort could also be directed toward studying the various applications of IoT technologies in the agriculture domain, such as precision agriculture, smart irrigation systems, etc. Implementation of state-of-the-art technologies like Big data analysis as well as Machine learning could open many avenues in future applications.

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