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The Development Trends and Challenges of Smart Water Management in China

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Abstract: Smart Water Management refers to the modernization of water services through the application of digital and information technologies. It has rapidly developed in China, demonstrating significant advantages. However, it also faces both internal and external challenges. Despite these challenges, Smart Water Management in China is presented with unprecedented opportunities driven by technological advancements, industrial progress, and the vast Chinese market. This paper provides a comprehensive analysis of the development of Smart Water Management in China, offering relevant recommendations on how to support it through policy measures.

Keywords: Smart Water Management, Chinese Water Management, Future Direction.

1. Introduction

1.1. The Development of Water Management in China

Water management refers to the sustainable development, utilization, and treatment of urban water resources—in simple terms, all water-related affairs within a city. China started relatively late in the field of water management. The earliest modern water management system in China was the Longyin Spring Water Project, constructed in 1879 in Lüshun, which was the first urban water supply project in modern China [1]. With the development of Chinese cities in modern times, major cities began constructing water management projects, but these projects were characterized by their fragmented and independent nature, lacking systematic planning. After the founding of the People's Republic of China, the pace of infrastructure construction accelerated, leading to systematic urban water management projects, significantly advancing China's water management. Following the reform and opening-up policy, China's cities experienced rapid growth, with increasing urbanization rates and ongoing development of water management projects. However, in some areas, this rapid development was accompanied by rushed construction, inefficient management, and passive maintenance, resulting in a bumpy path for China's water management. Entering the 21st century, with the explosive growth of urban populations and rising urbanization rates, the water management industry in China gradually matured through three stages: 1) automated water management, 2) digital water management, and 3) intelligent water management [2]. Nonetheless, traditional water management faces numerous challenges in the information age, primarily manifesting in three areas: urban flooding, urban water scarcity, and urban water pollution, which can be summarized as too much water, too little water, and polluted water.

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(1) Urban Flooding: Urban surface hardening and decreased permeability, coupled with the frequent occurrence of extreme rainstorms, have led to frequent urban flooding in China. Particularly since the 21st century, the frequency of urban flooding has risen across both southern and northern cities, whether in humid or arid regions.

(2) Urban Water Scarcity: With the rising urban population and total water consumption, water supply has struggled to meet demand, leading to a decline in per capita water resources, especially in arid and semi-arid regions where urban water scarcity is more pronounced.

(3) Urban Water Pollution: The rapid development of cities has brought prosperity but also pollution. The rushed construction of water management projects, coupled with inefficient management and passive maintenance, has led to urban wastewater treatment lagging behind the pace of development, resulting in the pollution of urban water resources.

Traditional water management, relying solely on reservoirs, pumps, pipelines, and wastewater treatment plants, is insufficient to address these issues. There is a need to imbue traditional water management with new intelligence—Smart Water Management.

1.2. Basic Characteristics of Smart Water Management

Smart Water Management builds upon traditional water management by integrating emerging information technologies such as the Internet of Things (IoT), big data, and artificial intelligence (AI), transforming traditional water management into an information-driven, digital, and intelligent system. This transformation enhances operational efficiency, reduces operational costs, and improves the quality of water management, leading to more scientific management practices.

Compared to traditional water management, Smart Water Management offers several advantages. By leveraging IoT technology, water systems can be remotely monitored and controlled, which enhances management efficiency, reduces labor costs, and minimizes safety incidents. The use of big data technology allows for the collection and analysis of vast amounts of data from various sources, enabling the creation of models through algorithms. This process enhances the efficiency and quality of supervision and provides scientific, intelligent, and precise guidance for water management projects. AI technology, through the use of AI algorithms, integrates massive datasets to predict and forecast potential issues, improving the operational efficiency of water systems and preventing system failures.

China has specific advantages in the development of Smart Water Management. First, the development of Smart Water Management in China is not lagging behind that of other countries. China's Smart Water Management is internationally competitive and not dependent on foreign technology. Second, China has accumulated rich experience in traditional water management and holds certain advantages in emerging information technologies such as IoT, big data, and AI. This experience and technological foundation support the rapid development of Smart Water Management. Third, China's advancing urbanization, now entering a stage of high-quality development, necessitates Smart Water Management to ensure water security.

However, there are limitations in the development of Smart Water Management in China. First, the development is uneven across the country. Due to disparities in economic development and the uneven distribution of technical talent, investments in Smart Water Management vary, leading to different levels of development in different regions. Developed regions experience rapid growth in Smart Water Management, while less developed areas see stagnation. Second, the development of Smart Water Management in China is not yet fully mature. For example, although Zhengzhou proposed the construction of a Smart Water Management system as early as 2016, the city still struggled to effectively handle urban flooding during the extreme rainfall on July 20, 2021, indicating that the development and construction of Smart Water Management in some cities are still incomplete [3]. Third, there is a shortage of professionals in Smart Water Management in China. The concept of

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Smart Water Management has only been around for about a decade, and due to its relatively recent emergence, few people have engaged in or committed to this field, resulting in a lack of specialized talent and limited opportunities for talent cultivation.

1.3. Summary

In summary, China's water management needs Smart Water Management. While there are both advantages and disadvantages in the development of China's water management, the path of developing Smart Water Management in China is filled with both challenges and opportunities. Given China's vast urban population, there is a significant demand for water management systems to ensure water security, making China a fertile ground for the growth of Smart Water Management. Therefore, the potential for Smart Water Management in China is immense.

2. Definition and Composition

2.1. Technological Background of Smart Water Management

The development of Smart Water Management has been a gradual process, evolving through four distinct stages: the automation stage, the digitization stage, the intelligent stage, and the smart stage. Due to varying economic conditions, levels of development, and talent reserves across different regions, the stage at which each water management system currently operates may differ. However, most systems have undergone technological transformations in alignment with these four stages.

The first stage is the automation stage, where water management systems introduced automation technologies and sensor technologies. By installing various sensors within the water management systems and utilizing automation methods, the accuracy of measurements and the efficiency of data collection were significantly improved, while reducing labor costs. This stage marked an increase in the automation level of water management systems.

The second stage is the digitization stage, where water management systems integrated digital and network transmission technologies. The use of network transmission technology enhanced the efficiency of data collection, transmission, and storage. Digitization in water management established operational platforms and databases, achieving initial digitization and informatization of the water management systems. This stage signified China's transition from automation to informatization in water management.

The third stage is the intelligent stage, where water management systems incorporated IoT technology. The intelligent water management system connects water facilities with management departments, forming an urban water IoT network. This integration enables real-time monitoring and management of water systems by management departments, strengthening the connection between water management authorities and local water operations. The intelligent water management system laid the foundational architecture for the development of Smart Water Management.

The fourth stage is the smart stage. Smart Water Management represents a new generation of information technology that has evolved from traditional water management. It not only retains the original technologies of traditional water management but also integrates emerging technologies such as 5G, IoT, big data, and AI, which are rapidly developing today. These technologies endow Smart Water Management with digital intelligence, providing strong technological support.

2.2. Technical Description of Smart Water Management

The technologies required for Smart Water Management can be categorized into four main types based on their processes and functions: data collection and sensing technologies, data transmission

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and processing technologies, data analysis and mining technologies, and intelligent decision-making and control technologies.

2.2.1. Data Monitoring and Collection Technologies

Data monitoring and collection technologies form the foundation of Smart Water Management. These are primarily used to monitor and collect various real-time water-related data. This category includes sensor technology, IoT technology, and automation technology. Compared to traditional water management, Smart Water Management offers real-time, automated, and diversified data monitoring and collection, providing the system with vast amounts of real-time, varied data. This enhances the efficiency of data monitoring and collection while reducing the labor costs associated with monitoring water conditions and collecting data. These technologies lay the groundwork for final intelligent decision-making by providing a robust data foundation.

2.2.2. Data Transmission and Processing Technologies

Data transmission and processing technologies are crucial to Smart Water Management. These technologies are mainly used for the transmission, storage, and processing of water-related data. Key technologies in this category include cloud computing, big data technology, and stream processing technology. Compared to traditional water management, Smart Water Management offers faster, more secure, and standardized data transmission and processing. These technologies ensure the secure transmission of data and enable the system to handle vast amounts of data efficiently. They also prepare the system for the next stage of data analysis by ensuring that data can be quickly and effectively processed, reducing the labor and material resources required for data handling.

2.2.3. Data Analysis and Mining Technologies

Data analysis and mining technologies are at the core of Smart Water Management. These technologies are used to analyze and interpret water-related data. To extract valuable information from the data, the support of artificial intelligence and big data technologies is required. By leveraging these technologies, smart water management systems demonstrate higher efficiency, automation, and intelligence in data identification and analysis compared to traditional water management systems. Smart water management uses AI and big data technologies to assess data quality and perform targeted analysis based on data characteristics, thereby providing a solid foundation for subsequent intelligent decision-making and control.

2.2.4. Intelligent Decision-Making and Control Technologies

Intelligent decision-making and control technologies represent the ultimate goal of Smart Water Management. These technologies provide rational decision-making and enhance the control over Smart Water Management systems. Smart decision-making and control in smart water management require the use of artificial intelligence, structural integration, and robotic intelligence technologies. By utilizing these technologies, smart water management systems offer greater intelligence, precision, and dynamism in decision-making and control compared to traditional water systems. AI technology allows smart water systems to simulate scenarios based on provided data and generate corresponding solutions. Meanwhile, structural integration and robotic intelligence technologies enable remote control and robotic operation of water systems, reducing the manpower and resources needed for maintenance and operation while ensuring the safety of personnel in harsh conditions.

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2.3. Business Logic Composition of Smart Water Management

The construction of a smart water management system is not achieved overnight; it requires a series of processes to build a complete system. Generally, this process is divided into eight steps: initiating a plan, conducting preliminary research, clarifying requirements, developing the framework, research and development, implementation preparation, installation and debugging, and actual operation [4]. The construction of a smart water management system is closely related to these processes. Preliminary research is a prerequisite, as it lays the groundwork for the system's development. After the preliminary research, it is essential to clarify the requirements, since the ultimate goal of the smart water management system is to meet these needs. Therefore, the requirements must be clearly defined before proceeding with further development. Once the requirements are clear, the framework of the system can be developed. Following the framework development, the system undergoes research and development based on the defined requirements, followed by implementation preparation. After the system is constructed, it must be debugged before it can be put into actual operation. This ensures the smooth operation of the smart water management system.

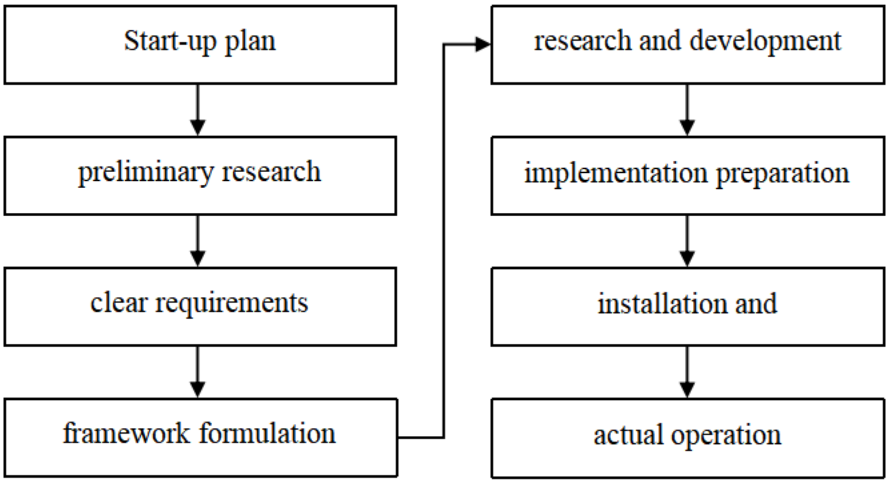

Figure 1: Flow chart of building a smart water system.

The smart water management system is primarily composed of five layers: the perception layer, transmission layer, judgment layer, decision-making layer, and processing layer.

The perception layer is the foundation of the smart water management system. It consists of automated sensors, monitoring drones, remote sensing equipment, and other devices. The primary function of the perception layer is to gather data from the water management system. This layer provides a vast amount of data, which serves as the basis for the operation of the smart water management system.

The transmission layer is a crucial component that ensures the reliable operation of the smart water management system. It is composed of 5G devices, fiber optic equipment, and other communication technologies. The main role of the transmission layer is to transmit the data collected by the perception layer. It provides a real-time, stable data stream for the system, along with security for data transmission.

The judgment layer is a key part of the smart water management system. It is built on big data platforms, cloud computing platforms, and similar technologies. The primary function of the judgment layer is to analyze and evaluate water-related data, extracting critical information. This analysis provides the decision-making layer with sufficient information to make informed decisions, aiding in the rational decision-making process.

The decision-making layer is the core of the smart water management system. It consists of AI platforms and similar technologies. The primary function of this layer is to make decisions based on the information provided by the judgment layer and to issue commands to the processing layer. The decision-making layer is the most critical part of the system's operation.

The processing layer is the terminal of the smart water management system. It is the most direct and crucial part of the system for fulfilling its functions and requirements. The processing layer is composed of automated operating systems, intelligent water management robots, and similar technologies. Its primary function is to execute precise and efficient operations on the water management system based on the instructions from the decision-making layer. This ensures the accurate and effective operation of the smart water management system.

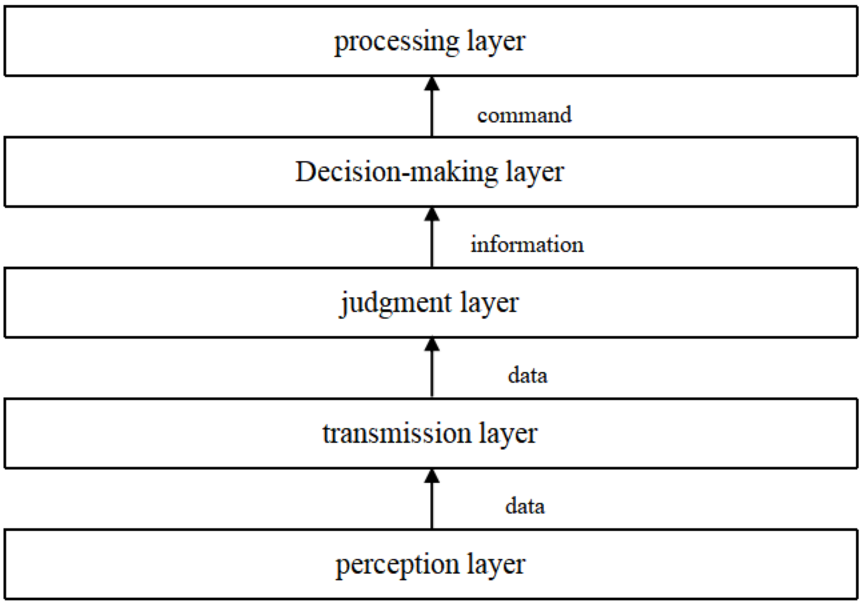

Figure 2: Composition of the water system.

3. Challenges

Smart Water Management faces numerous challenges, both from within the system itself and from the external environment. These challenges not only present difficulties for the development of Smart Water Management but also offer new opportunities.

3.1. Internal Challenges

Regarding the system itself, Smart Water Management encounters challenges related to innovative development and digital transformation, requiring continuous effort from water management professionals to overcome.

3.1.1. Challenges in Innovative Development

These challenges primarily revolve around the practical operation of the Smart Water Management system, technological support, and interdisciplinary integration. First, the resource-sharing mechanism within the Smart Water Management system is outdated. Resources within the system come from various institutions, and the data formats are inconsistent, leading to reduced resource integration and the creation of "information silos." This outdated resource management hinders the system from fully realizing its potential. Second, the development of technologies required for the

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Smart Water Management system is lagging. The technological advancements needed for the system are not keeping pace with its overall development, resulting in stagnation. Third, interdisciplinary integration within Smart Water Management is relatively weak. The system requires the convergence of multiple disciplines; however, the current level of interdisciplinary integration is insufficient to support the system's development effectively.

3.1.2. Challenges in Digital Transformation

These challenges are primarily related to the relationship between data and digitalization. First, the independent development of different parts of the Smart Water Management system lacks overall design coordination. The technologies required for various parts of the system differ, and the professionals involved come from diverse backgrounds, leading to communication barriers and a lack of understanding of each other's needs. This misalignment significantly hampers the digitalization of the system. Second, the digital infrastructure of the Smart Water Management system is weak.[5] The existing infrastructure is inadequate to support the system effectively, failing to meet the requirements of digital transformation. Third, the data collected by the Smart Water Management system lacks application value [5]. Due to weak digital infrastructure, most data suffer from delays and lack diversity and richness. Additionally, the absence of a unified design and the existence of "information silos" within the system result in data that lacks practical application value.

3.2. External Environmental Challenges

In terms of external environmental challenges, the development of Smart Water Management faces issues related to management models and long-term sustainable development. Addressing these challenges requires the concerted efforts of the government, businesses, and society as a whole.

3.2.1. Challenges in Management Models

These challenges are primarily observed on both the supply side and the demand side of water management. First, on the supply side, Smart Water Management systems face the challenge of collecting dispersed data from various water plants and forecasting water demand. An essential task for the system is to efficiently manage the operations of water plants, the functioning of storage facilities, and the direction of water supply while improving the efficiency of water distribution. This is a complex and arduous task, presenting a significant challenge for Smart Water Management. Second, on the demand side, the challenge is how to encourage users to accept Smart Water Management systems. For businesses, the concern is whether the system will increase or decrease their operating costs, which may lead to hesitancy in adopting such systems. For the general public, the introduction of a smart water system may disrupt long-standing habits, making it difficult for people to adapt. For instance, older adults might struggle to check water usage or pay bills online. Additionally, the introduction of a Smart Water Management system could lead to skepticism among the public. People might question how the system can determine household water usage without manually checking water meters, raising concerns about potential inaccuracies or fraud.

3.2.2. Challenges in Long-Term Sustainable Development

These challenges mainly involve the lack of multidisciplinary talent, inadequate policies, and insufficient coordination mechanisms. First, Smart Water Management suffers from a shortage of generalists who can bridge various disciplines. The professionals involved in building these systems come from different fields, leading to communication barriers and misunderstandings about each other's needs. This lack of effective collaboration hinders the development of Smart Water

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Management. Second, there is a lack of relevant policies to support Smart Water Management. Economic conditions vary across regions, leading to differing levels of emphasis on water management. In developed areas, ample government funding and a focus on water infrastructure provide greater opportunities for the development of Smart Water Management. Conversely, in less developed regions, limited government funds make it challenging to support the development and implementation of such systems, posing a significant challenge. Third, there is a lack of coordination mechanisms. The sources of information and data in water management are diverse. The smooth operation of a water system requires coordinated efforts across multiple departments, such as meteorology, urban development, and law enforcement. Since smart water management systems emphasize timeliness, rapid collaboration with various departments is even more critical. However, the current coordination mechanisms are no longer adequate to meet the needs of smart water systems, resulting in a lack of effective linkage mechanisms.

4. Opportunities and Future Directions

The opportunities and future directions for Smart Water Management primarily lie in three areas: technological development, industry growth, and market drivers. To ensure the sustainable development of Smart Water Management in China, it is essential to seize these opportunities and identify the right direction for development.

4.1. Technological Development

Technological development represents a significant opportunity for Smart Water Management. As the primary productive force, advancements in technology can offer new opportunities for Smart Water Management. Recently, emerging digital technologies and information technologies have made significant progress. These advancements provide a timely opportunity for the transformation of Smart Water Management. Several emerging technologies present important opportunities:

(1) Big data technology provides a solid foundation for the storage, processing, and analysis of data in Smart Water Management. It reduces both the time and labor costs associated with running the system while enhancing operational efficiency and quality.

(2) Artificial intelligence (AI) technology offers a technical basis for intelligent decision-making in Smart Water Management. AI technology utilizes algorithms to enable self-learning, allowing AI to make informed decisions and enhance the smart capabilities of water management systems.

(3) IoT technology supports connectivity and communication within Smart Water Management systems. By linking control, decision-making, and sensing components through IoT, the efficiency of water management operations is improved, and response times are shortened, aiding in the handling of emergency situations.

In addition to these technologies, future developments in Smart Water Management will also involve integration with generative AI, virtual reality (VR), and data visualization technologies. The direction for future development is to transform traditional water management into a digital, informational, and intelligent system through the application of these emerging technologies.

4.2. Industry Development

Industry development is a crucial opportunity for Smart Water Management. In an era of innovative development, various industries are undergoing transformation and upgrading. The transformation of the water industry provides new opportunities for the growth of Smart Water Management. To achieve a transition from extensive and high-energy consumption practices to efficient and low-carbon operations, Smart Water Management is essential. Compared to traditional water management, Smart Water Management is more efficient and consumes less energy. It offers more precise

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operation of water systems, highlighting its advantages in industry development. With increasing digitalization in Chinese society and the growing need for smart solutions across various sectors, Smart Water Management is a key step in the digitalization of the water industry. The water sector requires the support of Smart Water Management.

In terms of industry collaboration and development, the future direction for Smart Water Management is to continuously update and adapt based on local characteristics and industry needs. This approach will achieve long-term development in the water industry, focusing on smart and sustainable development.

4.3. Market Drivers

Market drivers represent a significant opportunity for Smart Water Management. In a market economy system, the market controls capital and resources. Compared to traditional water management, Smart Water Management has several market advantages:

(1) Smart Water Management has lower operational costs and higher efficiency compared to traditional methods. It can save substantial amounts of money and time, offering both cost and efficiency advantages.

(2) Smart Water Management excels in handling emergencies with much greater efficiency than traditional systems. The time from detecting an issue to emergency response is significantly shorter, giving Smart Water Management an edge in managing urgent situations.

(3) The level of intelligence in Smart Water Management is far superior to that of traditional systems. The increasing digitalization of Chinese society provides lasting momentum for the development of Smart Water Management. Traditional water management lacks the necessary developmental drive. Additionally, digitalization and smart solutions are the future directions for societal development in China, positioning Smart Water Management advantageously.

In terms of market drivers, mature Smart Water Management systems can gain a competitive edge in the market. The future direction for Smart Water Management is to adapt to the evolving needs of Chinese society and meet market demands, thereby continuously improving the digitalization and intelligence levels of the water industry.

5. Conclusion

The formation and development of Smart Water Management in China have been a gradual process. Smart Water Management is a new type of water management that, through informatization, digitalization, and smartification, integrates emerging information technologies such as the Internet of Things, big data, and artificial intelligence. With the increasing urbanization in China, the rise in societal intelligence levels, and the frequent occurrence of extreme weather events, the necessity for developing Smart Water Management is becoming increasingly evident. However, the development of water management faces challenges including impediments to innovation, obstacles to long-term development, chaotic management models, and difficulties in digital transformation. These challenges require the joint efforts of the government, enterprises, and society as a whole. Despite these challenges, Smart Water Management also encounters opportunities presented by the times. If Smart Water Management can seize these opportunities, its future development will be characterized by long-term, efficient, green, and sustainable growth.

With advancements in technology, industry development, and continuous market driving forces, China’s Smart Water Management is facing unprecedented opportunities for development. By capitalizing on opportunities related to high-tech advancements, industrial transformation, and market growth in China, the water industry can achieve digitalization, informatization, and smartification, thereby enhancing the speed and quality of Smart Water Management development.

This paper also has limitations. First, it is based on existing literature and lacks completeness in information. Second, the limited reference materials result in content that is not fully comprehensive and does not cover all the details of Smart Water Management development in China. Third, this paper only explores the development of Smart Water Management within China and does not conduct an in-depth study of its global development. Future research may focus on the development of Smart Water Management in developed countries.

References

[1] Hou, L. (2024). Digitalization and intelligence empower the innovative development of smart water management. China Science and Technology Industry, (06), 1-3. https://doi.org/10.16277/j.cnki.cn11-2502/n.2024.06.012

[2] Sun, G. (2011). Construction of water supply facilities in Lushun. Dalian Modern History Research, 8(00), 501-507.

[3] He, X., Li, Z., Guo, H., et al. (2016). Research on the construction and key technologies of the smart water management system in Zhengzhou. Hydraulic Informationization, (06), 61-66+72. https://doi.org/10.19364/j.1674-9405.2016.06.013

[4] Jiang, H., & Zhang, D. (2024). Construction plan and application of a group-based smart water management platform under digital transformation. Industrial Control Computer, 37(06), 122-124.

[5] Ni, W. (2024). Practice of smart water management construction in Tengzhou. Shandong Water Resources, (06), 4-6. https://doi.org/10.16114/j.cnki.sdsl.2024.06.027