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Development of Smart Water Management in China: Current Status, Opportunities, and Challenges

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Abstract: This paper analyzes the current status, opportunities, and challenges in the development of smart water management in China. Influenced by multiple factors, the traditional water management model is facing difficulties. Smart water management has emerged as a timely solution. China is in the phase of intelligent development. The development opportunities for smart water management include internal industry demand and benefits, as well as external policy support and technological drivers. However, challenges such as low internal management levels, lack of top-level planning, and difficulties in digital transformation pose significant barriers. To achieve high-quality and sustainable development, smart water management requires the improvement of standards, as well as region-specific planning. This will contribute to the rational use of water resources, effective prevention of water-related disasters, and the stable development of the socio-economic environment and ecological balance.

Keywords: Smart Water, Digital technologies, Current Status, Opportunities, Challenges

1. Introduction

Currently, global climate change is unpredictable, and natural disasters are frequent. While the economy is growing rapidly, the population continues to increase. Under the influence of multiple factors, the allocation of water resources, monitoring of water quality, and prevention of drought and flood disasters are facing severe challenges. The traditional water management model is insufficient to meet the diversified and complex demands of modern water resource management. The traditional allocation of water resources is based on conventional methods and administrative scheduling, implementing simple and rigid distribution plans. [1] It is unable to comprehensively analyze current water usage needs, let alone optimize resource distribution according to the best operational models. Traditional water quality information collection primarily relies on manual data gathering and analysis, which cannot provide real-time monitoring of water quality. Historically, most water body data collection was done manually. The vague accuracy of information and inefficient transmission of data hindered effective responses in case of emergencies. The development of new-generation information technologies has brought profound changes to traditional industries, leading to the emergence of smart water management, which provides new solutions to the problems encountered by traditional water management.

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Smart water management integrates technologies such as the Internet of Things (IoT), big data, cloud computing, and artificial intelligence with water management practices to achieve intelligent management of water facilities, efficient use of water resources, and precise prediction and prevention of water-related disasters. [2] The core of smart water management lies in the application of information technology in the water sector. Today, the maturity of information technology systems and the diversity of available technologies offer more possibilities for the development of smart water management. Take flood disaster prevention as an example: real-time data collected through water sensors and remote sensing satellites is transmitted to computers. After processing with big data and model simulation, the computer can predict the likelihood of flood disasters in the near future. Artificial intelligence, on one hand, calculates the optimal solution for disaster reduction using water management facilities and quickly mobilizes relevant flood storage areas and dam gates to prepare for the impending flood. On the other hand, it sends disaster warnings to the public through wireless networks or wired signals. Smart water management is an inevitable trend in the modernization of the water sector. The government places great importance on the development of smart water management in China, providing more opportunities for its advancement. By the end of 2021, the Chinese government introduced several policies to support the development of smart water management and proposed a series of plans. These plans emphasize strengthening the construction of smart water management in China through four aspects: building digital twin river basins, constructing the "2+N" water management intelligent business application system, reinforcing the water management cybersecurity system, and optimizing the smart water management security system. While China's smart water management construction has made significant progress, it still faces many challenges. For instance, issues related to data security and privacy protection, technology integration and compatibility, and high construction costs are prominent. Among these, the challenge of technology integration and compatibility is particularly significant, primarily due to the incomplete development of the smart water management standard system. This has led to difficulties in integrating hardware and software between digital twin platforms, information infrastructure, and supporting water management projects.

2. Components of Smart Water Management

2.1. Development Stages of Smart Water Management

The development of smart water management in China can be divided into three main stages. The first stage is the automation stage. The automation of water management systems is primarily reflected in information monitoring and equipment control. For example, smart metering is an embodiment of automation in China's smart water management. Before entering the automation stage, water utilities in China employed a large number of meter readers. These readers had to visit households to check water meters and record residents' water usage over a specific period. At the beginning of this century, China upgraded its water management systems and officially entered the automation stage. After this, data such as residential water consumption and urban water network flow began to be collected through sensors rather than manually. The operation of equipment also shifted to automation. Automated control systems can adjust the flow, water pressure, and other parameters of the network according to preset settings. The automation of water management saves a significant amount of manpower and resources, making the system operation safer and more reliable.

The second stage is the digitalization stage. This stage builds on the automation of water management and integrates simple digital information systems. The water management system at this stage can record, store, and process data, enabling digital construction and application. For instance, the construction of digital water management platforms allows users to access real-time information about the water network.

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The third stage is the intelligent stage, which is the current stage of China's water management system. Intelligent water systems aim to achieve collaborative and dynamic management operations through the comprehensive application of advanced technologies such as the Internet of Things (IoT), big data, artificial intelligence (AI), and cloud computing. Intelligent water systems not only significantly improve water resource management and utilization efficiency but also address some of the challenges faced by traditional water management systems.

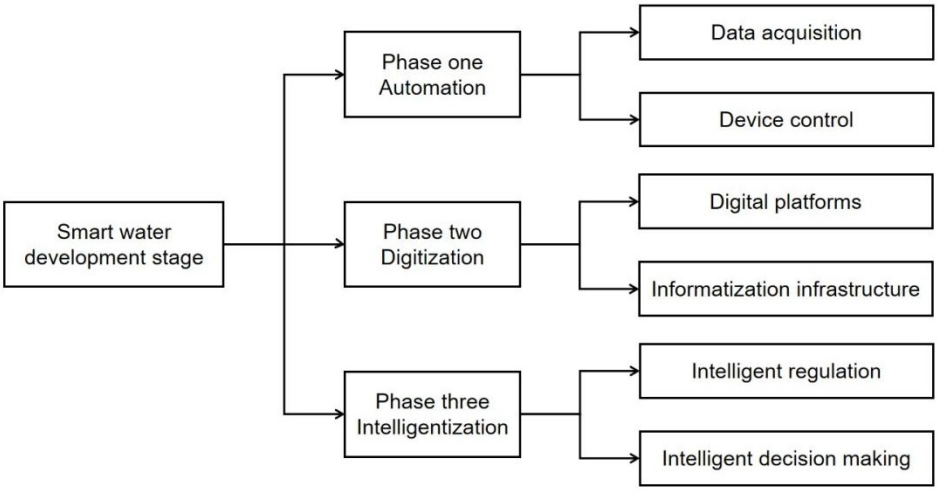

Figure 1: Different Development Stages of Smart Water Management

2.2. Key Technologies Involved

(1) Artificial Intelligence Technology: In recent years, artificial intelligence algorithms have been continuously improved. Traditional machine learning algorithms such as artificial neural networks (ANN), decision trees (DT), and random forests (RF), as well as deep learning algorithms like long short-term memory networks (LSTM) and gated recurrent units (GRU), play an important role in hydrological monitoring and forecasting. Computer vision-based detection methods such as Faster R-CNN, YOLO, and SSD have been widely used for detecting floating objects on water surfaces and identifying black, odorous water bodies. [3] Compared with traditional control algorithms, artificial intelligence algorithms show better performance and advantages.

(2) Remote Sensing (RS) Technology: Remote sensing technology uses sensors like aerial cameras, multispectral scanners (MSS), and thematic mappers (TM) to detect and measure various surface features and phenomena. Several remote sensing satellites currently applied in the water management sector include the Fengyun series meteorological satellites and the NOAA series from the United States, which provide meteorological data such as precipitation. Optical, thermal infrared, and microwave satellite series (such as MODIS, Gaofen, Landsat, and Sentinel) are used to invert key water-related factors such as land surface evapotranspiration, snow thickness, and soil moisture. Satellites like SWOT are used for precise monitoring of river and lake hydrological parameters, while gravity satellites like CHAMP analyze changes in land surface water storage. Altimetry satellites such as Cryosat-2, ERS series, and ICESat series are used to estimate surface water level changes in lakes and reservoirs. [4]

(3) Cloud Computing Technology: Cloud computing technology is applied in smart water management in areas such as big data storage and processing, as well as the scheduling and management of computing resource pools. Given that smart water systems collect and monitor large amounts of data, cloud computing is essential for storing and processing this data. Cloud computing

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integrates multiple computing resources (such as physical servers) into a resource pool and enables automated management. This enhances data processing efficiency while reducing costs.

The development of new technologies is a driving force behind the advancement of smart water management. The restructuring and utilization of information technology and data have injected new vitality into the traditional water management industry, while also promoting the transformation and upgrading of the water sector.

3. Development Opportunities

3.1. Internal Opportunities

(1) Development Requirements of the Industry Itself: In the current social and environmental conditions, the water management industry needs to develop in the direction of high quality and sustainability. In terms of high-quality development, urban and rural water systems bear the important tasks of water supply and drainage. This includes ensuring that residents have access to high-quality tap water, safeguarding flood disaster prevention, and securing water supply safety. In terms of sustainable development, water systems are responsible for the management and allocation of water resources. This requires a well-established sewage treatment system, allowing for the recycling of wastewater, as well as reasonable allocation of water resources to ensure adequate ecological water flow and promote ecological restoration.

(2) Smart Water Management's Benefits in Multiple Areas: Smart water management can generate benefits across various sectors such as economic, ecological, and social aspects. [5] For example, with intelligent water meters: traditional mechanical water meters faced issues such as high manual meter reading costs, poor data accuracy, and difficulty accessing households, leading to the rise of smart water meters. Smart meters reduce operational costs for water utilities, improve resource utilization, and generate economic benefits. They also make life more convenient, enhance urban management, and bring social benefits. In terms of industrial and agricultural water use, smart meters contribute significantly to water conservation, resulting in ecological benefits. Smart meters represent just a small part of smart water management, which can generate considerable benefits across many other areas.

3.2. External Opportunities

(1) China's Active Promotion of Water Industry Transformation: China is actively advancing the transformation of the water management industry and has introduced numerous policies to support this effort. China has proposed promoting the construction of new smart cities in a hierarchical and classified manner, including measures to promote the comprehensive development of the Internet of Things (IoT) and accelerate the construction of a nationwide integrated big data center system. [6] Additionally, China emphasizes the need for a comprehensive, basin-wide approach to water resources, aiming to optimize water resource allocation and improve flood and drought disaster prevention capabilities. Furthermore, China is vigorously promoting the construction of a Digital China. During the transformation process, the Chinese government has actively communicated with relevant industries, introducing many exploratory policies and guidelines. These initiatives have created a favorable policy environment for the development of smart water management.

(2) Technology-Driven Development: One of the key drivers of smart water management development is technological advancement. The rapid development of technologies such as the Internet of Things (IoT), Geographic Information Systems (GIS), cloud computing, big data, and artificial intelligence (AI) offers new possibilities for smart water management. The integration of these technologies strengthens the functionality of smart water management systems, makes decision-making more reliable, and enables smarter operations. Moreover, with the development of

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information systems, a new generation of the digital economy is emerging. The combination of digital economy and the real economy is driving the accelerated transformation of traditional industries and the real economy. Smart water management is an inevitable trend for the transformation and upgrading of the traditional water management industry, and the smart management platforms required by the new economic system are equally applicable to the development of smart water management.

The internal driving forces for the development of smart water management include the industry's own development requirements and the significant benefits brought by smart water management. Favorable policies and the advancement of relevant technologies create a favorable external environment for the development of smart water management.

4. Development Challenges

4.1. Internal Challenges

(1) Low Management Level and Efficiency: At present, smart water management faces issues related to low management levels and efficiency. As a traditional industry, the water management sector tends to have an extensive management model. During the transformation to smart water management, the updating of management models has not kept pace with the industry's transition, and some outdated management practices persist. For example, there is poor synergy between the various modules within smart water management systems, and the collaborative mechanisms are not well-developed. Therefore, the management model needs optimization.

(2) Incomplete Interconnection of Operational Service Chains: The water industry’s inherent diversity dictates that its digital transformation must adopt a holistic perspective. If only specific segments or regions undergo digital transformation, the impact on improving overall operational efficiency, service quality, and resource optimization will be minimal. Smart water management needs to quickly establish a complete, integrated, and interoperable service chain.

(3) Aging Workforce and Insufficient Talent Training and Reserves: In the water management sector, the current workforce is aging, and many workers are accustomed to traditional water management models and techniques. Their understanding and ability to grasp emerging smart water technologies are limited, leading to insufficient innovation during the construction and promotion of smart water management systems. Moreover, as an interdisciplinary field that combines water management and information technology, the number of specialized talents in smart water management is insufficient to meet the rapid development needs of the industry. This limits the innovation vitality and development potential of the entire smart water management industry chain.

4.2. External Challenges

Although policies provide some support, smart water management lacks top-level leadership and planning within the water industry. Except for the construction of water treatment plants, other aspects of the water industry possess natural monopoly characteristics. The high cost of infrastructure construction and long service life of assets, such as water pipelines, often mean that their duplication is considered inefficient from an economic standpoint. As a result, the high cost and difficulty of independently exploring smart water management solutions in various regions and enterprises make it challenging to change the overall industry environment. The lack of top-level leadership also leads to a vague development direction for smart water management, preventing efficient resource integration and sharing. These factors contribute to low development efficiency and slow progress in transforming the industry.

Information technology began its upgrade and transformation in the computer industry, and the development of smart water management naturally involves a process of digital transformation. The

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cross-industry application of information technology often leads to difficulties in the digital transformation of water management. On one hand, the traditional systems in the water industry are large and complex, with poor compatibility with digital technologies, making it difficult to quickly adapt to changes brought by new technologies. On the other hand, the application of digital technologies in water management faces the challenge of data integration. Data from different sources often have inconsistent standards and varying quality, making it difficult to construct accurate and effective digital models for water management.

5. Conclusion

Global climate change, population growth, and other factors have posed significant challenges to water resource management, and traditional water management models are struggling to meet the increasing demands. The development of next-generation information technologies has driven the emergence of smart water management, offering new solutions to the problems faced by traditional water management systems. The development of China's water industry has gone through the stages of automation, digitization, and now, intelligentization. Currently, smart water management is in the intelligentization phase and is developing steadily.

Numerous opportunities are driving the development of smart water management. Internal opportunities stem from the industry's own development needs and the various benefits brought about by smart water management, while external opportunities include policy support and technological advancements. Both internal and external opportunities work together to propel the development of smart water management. However, there are also many challenges. Internally, the industry faces issues such as low management levels, incomplete interconnection of planning and operational service chains, and problems related to workforce structure and talent reserves. Externally, challenges include the lack of top-level leadership and planning, as well as difficulties in the seamless integration of digital transformation.

Smart water management will continue to progress along the path of digitalization. Efforts should focus on improving the standard system for smart water management and resolving issues related to technology integration and compatibility. This will lay a solid foundation for digital transformation. Local governments must develop smart water management plans based on their own specific conditions, such as water resource distribution, water infrastructure status, and economic development levels. During the development process, it is essential to seize opportunities and actively address challenges. This will drive the high-quality, sustainable development of smart water management, providing stronger support for the rational use of water resources and effective flood disaster prevention, thus ensuring the stable development of the economy and the balance of the ecological environment.

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