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# Study on the Countermeasures of Ensuring Drinking Water Security in Shanshan County of Xinjiang Autonomous Region, China †

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**Abstract:** China has paid more attention to improving urban and rural drinking water security in recent years. Ensuring the security of drinking water in urban and rural areas is a fundamental condition for protecting the basic interests of the public, and it is also an important aspect of building a moderately and all-sided prosperous society in China. Taking the Shanshan County in Turpan City of Xinjiang Autonomous Region as an example, this study analyzed the countermeasures of ensuring drinking water security. Firstly, this paper discusses the status quo of drinking water security in Shanshan. In terms of urban drinking water, problems are shown as follows: (1) drinking water sources are polluted to varying degrees; (2) water treatment technologies lag behind when compared to the social development; (3) there is a high leakage rate in the water supply pipe network; and (4) there is low emergency handling capability. In terms of rural drinking water, small-scale drinking water security projects are on low construction standard, which has resulted in low water supply guarantee rates and poor water source protection and water quality supervision. Secondly, based on an analysis of current problems, the quantity of water resources guaranteed is put forward. This paper divides Shanshan County into three units—the Karuqi area, the Ertanggou area, and the Kekeya area—based on urban or rural land use. This paper proposes the optimal distribution of regional water plants and a water supply network for the optimal allocation of regional water resources. Thirdly, for water quality improvement, a corresponding water purification program is developed to solve raw water quality problems, which includes centralized and decentralized water quality treatment, as well as an intelligent water flow control process. At the same time, management measures such as water source conservation and risk control measures are proposed in order to promote the security of drinking water. This paper also puts forward relevant strategic suggestions for ensuring the security of drinking water in Shanshan County, which includes enhancing equipment for the project, modulizing the system of devices, developing instrumentation of the management system, and establishing an intelligent water management platform. This study acts as a reference for solving problems of drinking water security in urban and rural areas in arid regions in Northwest China and similar areas around the world.

**Keywords:** drinking water security; water resources allocation; pipe network construction

## 1. Introduction

Ensuring drinking water security in urban and rural areas is an important part of building a well-off society in an all-around way, and it is also a basic requirement for safeguarding the fundamental interests of the general public. However, the current urban and rural drinking water security in Northwest China is facing a serious situation. There is a series of problems in engineering technology and system mechanism. For example, the water supply guarantee rate is low; the amount of water is insufficient; water resources are polluted; water purification capacity is relatively backward; and emergency capacity is low [1]. To meet the requirement of the central government to further urban–rural development and establish the assurance of drinking water security characteristic of well-off societies, it is necessary to further accelerate the process of establishing drinking water security projects for people and livestock in the northwest region in China. In addition, the reform of the management system for water supply projects needs to be intensified. Improvements in long-term project operations and socialized services should be made as well. Moreover, strengthening the protection of water resources and the assurance of water quality, improving the living conditions and environment of rural residents, and increasing residents' health level are also important establishing a new socialist countryside and a moderately prosperous society [2]. Taking Shanshan County of the Turpan Area in the Xinjiang Autonomous Region as an example, this study aims to further improve the regional urban and rural water supply guarantee rate, the water quality pass rate, the popularization rate of tap water in rural areas, and project operation and management. Measures such as improving the quality and efficiency of drinking water security, promoting the integrated management system of urban and rural water supply, and promoting comprehensive, coordinated, and sustainable eco-social development of urban and rural areas in the region should be taken so as to build a model for ensuring drinking water security in counties of Northwest China.

## 2. Study Area and Data

Shanshan County is located at the southern foot of Bogda Mountain in the eastern part of the Tianshan Mountains, and it is also in the south of Turpan basin. It lies between 89°30′28″~91°54′00″E and 41°12′10″~43°33′00″N, with a total area of 39,500 km$^2$. Shanshan County has a temperate inland desert climate. The average annual rainfall is less than 26 mm. The local river system is constituted of mountain streams: Ertanggou, Kekeya, and Karuqi from the west to the east, respectively. Due to the tectonic uplift of Huoyan Mountain, Shanshan County is divided into two hydrogeological units, namely the northern and southern basins. The groundwater in the northern basin is dominated by a phreatic aquifer, and the south basin is dominated by a confined aquifer. Shanshan County has five townships, five towns, and a horticultural market. By the end of 2014, the county's total population had reached 242,700, the agricultural population of which accounted for 74.90%.

Based on the status of urban and rural drinking water, this study presents basic economic data such as social and economic indicators and the development and utilization of water resources in Shanshan County, which is mainly based on data published by the Statistics Bureau of Turpan Prefecture and Shanshan County. These data include the Statistical Yearbook of Turpan Prefecture, the Shanshan County Drinking Water Security and Network Transformation Report, the overall planning of county development, land use planning, and county water conservancy development planning. When statistical data was lacking, field investigations and surveys were conducted, and the data used were carefully reviewed and amended to ensure that the information used was true and scientific

## 3. Methods

Based on the current security status of urban and rural drinking water in Shanshan County, we aimed to optimize the allocation of water resources, waterworks, and pipelines, enhance water purification projects, and improve management system and mechanisms by providing solutions for ensuring water quantity and quality and for management problems (Figure 1) [3]. Based on the forecast of regional water supply and water demand, we optimized the allocation of water resources and achieved a balanced spatial distribution of water resources and provide water resources with support for the layout of new drinking water projects. According to differences in the statuses of various water supply projects and drinking water security systems in the region, distribution and optimization of waterworks and water supply networks were carried out [4]. To solve existing problems and achieve the development goals related to drinking water security, new technologies, new processes, new materials, and new equipment need to be used to build intelligent monitoring and control programs for better quality and efficiency of water purification projects, which includes the automatic control of waterworks, the intelligent management of water purification processes, and smart online water monitoring. For situations where there is a lack of drinking water security management, it is proposed that water source protection and risk prevention be strengthened and water supply security ensured. Here, enhancing the equipment for projects, modulizing systems of devices, developing instrumentation for management systems, and establishing intelligent water management platforms of drinking water security protection are achieved through collection strategies of engineering, technology, and management so as to advance the Urban and Rural Drinking Water Security Project in Northwest China [5].

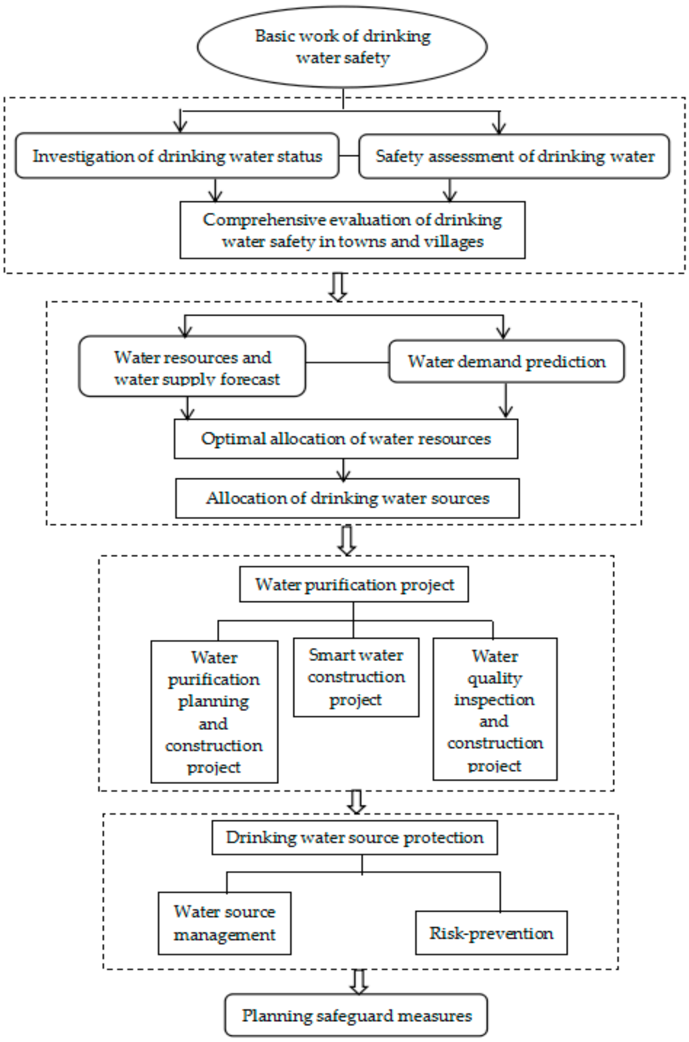


**Figure 1.** Technical roadmap of the study methods.

## 4. Results and Discussion

### *4.1. Analysis of the Status Quo*

Water in Shanshan County is supplied by two water supply companies, namely The First Water Supply and Drainage Company and The Second Water Supply and Drainage Company. The water source of The First Water Supply and Drainage Company is groundwater. The Second Water Supply and Drainage Company's water source used to be deep underground well water [6], but it has gradually changed to surface water. Shanshan's rural drinking water is primarily a centralized water supply. The rural supply network basically covers all villages and towns. There are mainly four waterworks: the ShanNan Water Work, the Qiketai Water Work, the Suburban Water Work, and the Lianmuqin Water Work. Ensuring drinking water security in Shanshan is very difficult. In 2014, the number of people without safe drinking water in towns and villages was about 416,000, which accounted for 16.5% of the total population of the county. In general, problems include water pollution to different degrees, poor water purification treatment technology, a higher water supply pipe network leakage rate, insufficient water quality monitoring and detection ability, and poor emergency response. The main problem is that the water quality is not up to standard. The water pollution is mainly due to domestic sewage and industrial waste water discharge. The water quality test results showed that, for two consecutive years, the total numbers of CFUs in 80%~85% of the drinking water engineering was beyond the limit, and the turbidity, chroma, chlorides, and total hardness levels were all below standard.

### *4.2. Water Resources and Water Supply Optimal Allocation*

Through the analysis of available surface water and groundwater supply at Shanshan, as well as the analysis of the current status of the water supply project, the status of the water supply in the region was evaluated. It is also necessary to predict the socio-economic conditions in the region and thus the future water demand of residents, agriculture, industry, and tertiary industries [7]. Taking water saving in production and living into account, water resources will be allocated between water use units and water users (domestic, industry, agriculture, animal husbandry, fisheries, and ecology) following optimal allocation (see Table 1). At a frequency of 50% (almost a long-term average level), the actual water supply in the status quo is $42{,}175.7 \times 10^4$ $m^3$, of which $10{,}685.1 \times 10^4$ $m^3$ is overexploited, and groundwater over-mining is even more serious during dry years. In 2020, it is planned that water sources be broadened and water use in agriculture and industry (especially agriculture) be reduced by, for example, further developing agriculture water saving facilities so as to improve water use efficiency. Through the optimal allocation of water resources among the various water use units, it is possible to ensure a more adequate domestic water supply and provide water security for urban and rural drinking water. The balance of water supply and demand at Shanshan is shown in Table 1.

**Table 1.** Supply and demand balance table of current and planned years in Shanshan under 50% frequency ($10^5$ $m^3$).

| Source of Water | Type | Current Year Allocation | Optimal Allocation of Planning Level Year | | | |
|---|---|---|---|---|---|---|
| | | Shanshan | Ertanggou | Kekeya | Karuqi | Shanshan |
| **surface water** | Domestic water | 42.88 | 48.50 | 0.00 | 0.00 | 48.50 |
| | Industrial water | 421.61 | 52.53 | 103.50 | 244.29 | 400.31 |
| | Conventional farmland | 1147.59 | 131.27 | 382.82 | 46.33 | 560.42 |
| | Conventional garden | 4802.16 | 833.32 | 1415.20 | 98.58 | 2347.09 |
| | Efficient farmland | 2295.72 | 720.99 | 1420.14 | 280.77 | 2421.89 |
| | Efficient garden | 5482.34 | 2247.86 | 2695.62 | 847.48 | 5790.97 |
| | Animal husbandry water | 53.15 | 18.72 | 19.81 | 14.62 | 53.15 |
| | Fishery water | 48.00 | 18.00 | 15.00 | 15.00 | 48.00 |
| | Ecological water use | 32.20 | 8.90 | 10.00 | 23.40 | 42.30 |
| | Subtotal | 14,325.64 | 4080.09 | 6062.09 | 1570.47 | 11,712.65 |
| **groundwater** | Domestic water | 808.65 | 436.54 | 328.32 | 152.92 | 917.78 |
| | Industrial water | 983.75 | 122.56 | 241.49 | 570.01 | 934.07 |
| | Conventional farmland | 2022.30 | 288.13 | 544.10 | 101.69 | 933.93 |
| | Conventional garden | 8782.14 | 1829.04 | 2011.43 | 216.37 | 4056.84 |
| | Efficient farmland | 4230.04 | 1582.48 | 2018.45 | 616.26 | 4217.19 |
| | Efficient garden | 10,653.63 | 4933.80 | 3831.31 | 1860.13 | 10,625.24 |
| | Animal husbandry water | 79.73 | 28.08 | 29.72 | 21.92 | 79.73 |
| | Fishery water | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Ecological water use | 289.80 | 80.10 | 90.00 | 210.60 | 380.70 |
| | Subtotal | 27,850.03 | 9300.74 | 9094.83 | 3749.91 | 22,145.48 |
| Total water supply | | 42,175.67 | 13,380.83 | 15,156.92 | 5320.38 | 33,858.13 |
| **Groundwater overdraft** | | 10,685.14 | 2434.78 | 1198.98 | 1346.83 | 4980.59 |

### *4.3. Waterworks and Pipe Network Optimization Layout*

On the basis of water supply source protection, the optimal layout and design of urban and rural waterworks and water supply network has been carried out [8]. The scale of rural tap water supply was calculated by considering the water for domestic use in rural areas, the water for livestock use, the water for township enterprises, the amount of water leaked from the pipe network, and the amount of water consumed by the waterworks; the urban tap water supply size calculation considers urban domestic water, industrial water, and the use of waterworks themselves. By the rural water supply estimation, the total water supply of the two waterworks in the towns should be up to 32,600 $m^3$/d, and the total water supply of four water plants in rural areas should reach 8900 $m^3$/d by 2020. Considering the rapid population growth in the region, the existing waterworks will be rebuilt in the near future to fully meet needs. When conditions permit, industrial and domestic water supply may also be realized in a decentralized manner to reduce water supply costs. Investigations showed that the Shanshan water main line pipe network basically covers the whole territory, so future pipe network extension will be based mainly on the branch pipe network and the pipe network to each house. For those places where there are indeed difficulties in extending the pipe network, only a decentralized water supply can be adopted. Appropriate water supply measures should be implemented according to local conditions; small independent water supply systems with water purification and disinfection facilities should be built in rural areas. The shallow groundwater areas should use a shallow water supply project; mountain stream areas should use water diversion facilities. Karez projects could be used in areas where there is water shortage or where development and utilization are difficult.

### 4.4. Water Purification Project Design

From the analysis above, it is obvious that current water treatment technology is relatively poor, and the water quality is not up to standard. Besides, the water treatment automation degree is low as well. According to the status quo of water source and water treatment technology, when the water purification project was designed, hydroinfomatics technologies like the automation control of plant's operating processes, the intelligent control of water purifying processes, and the intelligent online water monitoring was applied in water purification engineering through internet, the internet of things, and cloud computing technology to promote the equalization of the project, the modularization of the equipment, the instrumentation of management, and the intelligence of the internet of things.

#### 4.4.1. Equipment and Modularization of Water Purification Project

Traditional drinking water projects have problems such as high workloads, high operating costs, and difficult maintenance, while integrated water purification engineering facilities are suitable for water supply plans for areas that lack water resources, have diversified water pollution, or are economically underdeveloped. Standard modular design can be used for different water quality and construction conditions and can deal with a variety of water pollution problems comprehensively. Each module can be highly integrated through structure optimization to minimize occupied space. One centralized water supply plan is to select a centralized water source with standardized water quality and stable water volume and supply the water via a distribution network. A centralized water supply plan should be adopted for areas with relatively large populations and high water demand such as Shanshan. As for the plan, raw water enters a reservoir through a water intake structure; the reservoir here plays a role of adjusting water quality and quantity. After that, the water in the reservoir is lifted by the water pump to enter the subsequent treatment units. The coagulant is added into the water before it enters a pipeline mixer so that the colloids, suspended solids, microorganisms, and other organic and inorganic matters in the raw water will be flocculated through the adsorption of an electric compression layer and bridge formed by the coagulant. Then, water after flocculation enters the high-efficient integrated water purifier for further flocculation reactions. Later, separation, precipitation, filtrations, and water substance removal will be done. The fully automatic operation of the equipment is important for achieving the automatic management of the water plant. The middle reservoir also plays the role in regulating water quantity and water quality. Water in the middle reservoir is lifted by the booster pump to enter subsequent treatment units as well. During screening process by ultrafiltration membrane, the pressure difference between the two sides of the membrane acts as a driving force, and the ultrafiltration membrane acts as a filter medium. When water flows through the surface of the membrane, only water and small molecules can pass through the micro-pore, which is closely set on the membrane surface and becomes a permeate liquid. This process will help to achieve the aim of purification, separation, and concentration of water. Besides, fully automatic disinfection device mainly contains chlorine dioxide is used for sterilization, and the device consists of a main engine, a material tank, a water ejector, and a pressure gauge with electric contact. If users have certain demand regarding to the device, it can be automated and networked by customizing related program. As for the decentralized water supply plan, it is adopted in local areas that suffers from specific pollutant. In this plan, water plants and pipelines will be built for sub-quality water supply. As for different water quality problems, the steps of the treatment may include a high-fluorine water treatment process, a brackish water treatment process, and a water treatment process of iron and manganese removal.

#### 4.4.2. The Instrumentation and Intelligence of Project Management

(1) Automatic Control System of the Waterworks Operation Process

The main controller of the automatic control system in the operation process of the water plant adopts a high-performance programmable controller, which constitutes a secure and stable industrial network control system. The system consists of an intelligent water access terminal, an intelligent water terminal, an intelligent water supply terminal, a water quality monitoring terminal, a pipe network monitoring terminal, and a water control terminal.

The intelligent water intake terminal is installed in the water source or the water intake terminals of the waterworks for real-time monitoring and protection of the water intake equipment, and the water is delivered from the water source or the water intake terminal to the water purification system. The water purification system of the waterworks utilizes the intelligent water-making terminal; it integrates process requirements, which can automatically and intelligently regulate the operation of water purification devices as well as monitor and protect the devices in real time, so as to ensure the water volume and water quality of the water purification equipment. The water supply terminal of the waterworks is equipped with an intelligent water supply terminal; the terminal can intelligently control the water supply devices to supply qualified water to the users through constant pressure or constant flow and can timely monitor and protect the water supply devices at the same time. The water intake terminal, the water supply terminal, and the pipe network of the waterworks are equipped with the intelligent water quality monitoring system, which monitors the water quality indicators in real time. The pipe network within the water supply scope of the waterworks has a pipe network monitoring terminal that monitors the running status of the pipe network and transfers the pipe network operating data back to the central control room in real time to achieve quantitative management of the pressure and flow for the water supply. The water control terminal monitors the water pressure and the water flow for users in real time to ensure the satisfaction of the users' demands.

(2) Intelligent Control of the Water Purification Process

The intelligent control technology of the water purification process combines automatic control technology, intelligent monitoring, and management technology organically, forms the integrated solution of the intelligent control system of the water purification plant. Water quality parameters are promptly displayed. With the networking module, the water quality parameters of water sources in Shanshan are monitored in real time, displayed, and stored in a PC computer in the network center room and the smart water platform. Shanshan's six water plants apply real-time monitoring in production, and the water purification process is shown in pictures on a PC computer dynamically and displays the changes in water quality index, the water purification process, the equipment status, the water flow direction, and the water supply data. Through the accumulation and analysis of data, the real-time trend curve and the historical trend curve can be generated as needed.

Waterworks in Shanshan automatically collect data of the water purification process and automatically generate statistical analysis reports with the intelligent control system. The data reports can be exported at any time, which provides first-hand information for water plant management decision-making.

The Shanshan Central Control Room has set alarms for the abnormality, fault, diagnosis, and prompt failures in water quality monitoring, the equipment, or the pipeline to facilitate management in a timely manner to avoid some possible problem cases .

(3) Intelligent Water Online Monitoring System

An intelligent water online monitoring system employs Internet of Things (IoT) technology and helps to improve the level of automation (Figure 2d). An intelligent water online monitoring system includes the following:

(1) On-line water quality monitoring of water wells.
Real-time monitoring and feedback of water sources is conducted, and water pollution information is sent in the form of text messages.
(2) On-line monitoring of water quality.
Water level, water flow, water pressure, turbidity, conductivity, pH, dissolved oxygen, residual chlorine, toxicity, and other parameters are monitored to ensure water supply safety.
(3) Online monitoring of water supply network.

The water supply network of six waterworks in Shanshan employs on-line monitoring, which helps to monitor the water pressure, water flow, water quality changes in the water supply network, residual chlorine at the end of the pipe network, and the other relative parameters (Figure 2).

Six waterworks control centers in Shanshan can have a dispatch information platform. Based on the daily pipe network data, the target for the next day will be set up. Relying on these data, the platform generates scheduling solutions to assist in water network operational optimization scheduling management. Data is shared through the network, and the production scheduling data can be directly used in an office automation system to integrate monitoring, control, and management. At the same time, an intelligent water online monitoring system has an early warning and emergency management mechanism of pollution incidents. Combined with the IoT module, the spatial and attribute data of the water supply network, and the drainage, are taken as the core with advanced computer software technology, communication technology, and graphics processing technology; a timely and stable alarm emergency management system can be established. Based on a large amount of data, statistical analysis of water quality is conducted to provide decision support for the treatment of water pollution incidents and ensure the safety of water for people in the region.

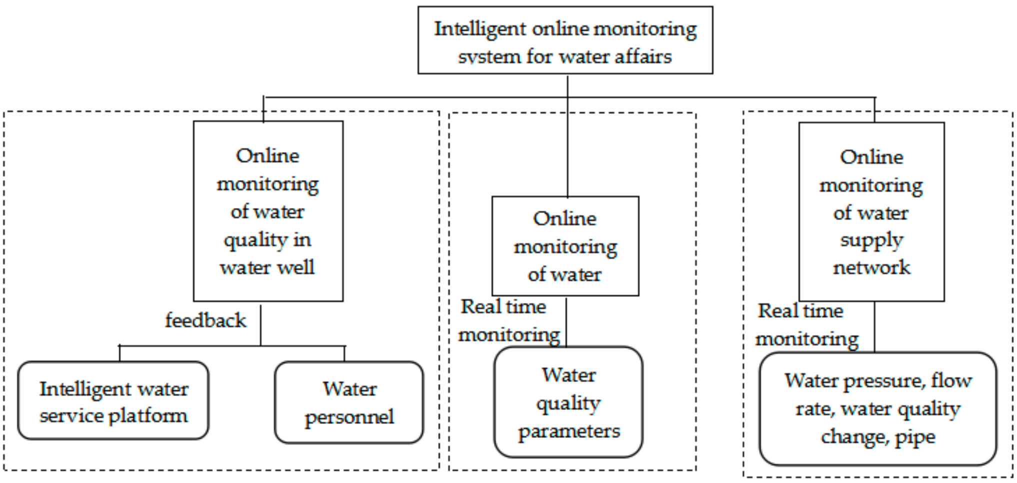


**Figure 2.** Flow chart of online monitoring system for intelligent water affairs.

### *4.5. Water Protection and Management*

Water conservation is long-term and crucial. It is necessary to strictly implement the Environmental Impact Assessment (EIA) of building and planning projects. It is forbidden to enter into protected areas with newly built projects that pollute drinking water. In addition, it is important to supervise original enterprises in protected areas of water sources and conduct inspections from time to time to standardize pollution discharge. Agricultural sources of pollution should also be supervised. Livestock and poultry breeding surveys can promote the use of organic fertilizer on farmland. Appropriate precautionary measures can strengthen investment in infrastructure for drinking water sources. Solid waste, sewage, and garbage can be rectified. dynamic monitoring of groundwater as well as the protection of the development and utilization of Karez wells need to be improved [9].

## 5. Conclusions

Based on the current situation of drinking water security in urban and rural areas in Shanshan county, this study puts forward a plan to strengthen its water supply and water quality assurance, which is to improve the water supply guarantee rate of drinking water through the optimal allocation of water supply and water plants, and a pipe network optimization layout. Water purification project quality and efficiency can be improved by enhancing equipment, modulizing devices, developing the management system, and establishing intelligent water management platforms to achieve sound water management. We also suggest corresponding management measures for water source protection. An intelligent drinking water security protection project is important for the integration of information resources and the intelligent utilization of water. Such a project would comprehensively improve the abilities of water management and public service, enhance the quality of people's lives, and promote the clustering and development of related industries.

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