ISSN 2616-5872 Vol.6, Issue 6: 19-25, DOI: 10.25236/AJEE.2024.060603

Research on water supply model, technology and long-term management mechanism—A case study of rural China

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Abstract: *The drinking water in rural China has some problems, such as poor protection of water source, backward purification technology and equipment, high leakage rate of water supply network, high risk of secondary pollution, and imperfect operation and management mechanism. How to improve the water quantity and quality assurance ability of drinking water from the source to the tap has become an urgent problem to be solved. This study summarizes the selection of rural water supply mode, key technologies and applications of conventional and unconventional water supply, and long-term management measures, and compares the water supply mode of northwest and southeast China, summarizes successful experience according to different regional characteristics, and strengthens the leading demonstration. In order to realize the long-term operation of rural safe drinking water project, the relevant countermeasures and suggestions are put forward.*

Keywords: *rural drinking water, operation management mechanism, water supply model, key technology, regional characteristics*

1. Introduction

Since the "11th Five-Year Plan", with the acceleration of China's new rural construction, the focus of rural water supply work has shifted from rural drinking water difficulties to solving rural drinking water safety problems, and the level of water supply security for 270 million rural people has been improved, the proportion of rural large-scale water supply projects covering the rural population has reached 56%, and the penetration rate of tap water has reached 87%. The guarantee of water supply in rural areas has been significantly improved.

However, with the sharp rise in the number of rural drinking water projects, there is a phenomenon of "heavy construction and light management" in the process of construction and development. In addition, China's rural drinking water projects are small and scattered, and the terrain and geological conditions are complex, leading to a series of problems. These problems include the inability of management to keep up with construction, improper use of water sources and inadequate protection of water sources, serious leaks in early water supply networks, lack of effective revenue management models for rural water supply, and difficulties in accessing special water quality in western and coastal areas. At the same time, the water purification process and integrated equipment are relatively backward, and the level of intelligent and information supervision technology is also low.

The leakage rate of water supply networks in some areas is as high as 20% to 30% [1], which seriously affects the effective use of water resources and the efficiency of water supply. By the end of 2019, there were more than 10 million rural water supply projects in China, and only 18,300 water supply projects for 10 million tons and urban extension projects, with the water supply service population accounting for 51% of the total water supply service population [2].

In addition, the economically developed eastern regions of the rural drinking water infrastructure construction and maintenance management is relatively perfect, while the central and western regions of China's rural drinking water safety is relatively backward, drinking water safety problems there are many hidden dangers. In view of rural water supply model, technology and long-term management mechanism, domestic and foreign scholars have carried out a lot of research.

At present, there are three main water supply modes in rural areas: urban and rural unified water

ISSN 2616-5872 Vol.6, Issue 6: 19-25, DOI: 10.25236/AJEE.2024.060603

supply, small centralized water supply and decentralized water supply. In recent years, the water supply model of "urban-rural integration, overall planning, state-owned holding and intensive management" has gradually attracted attention. Urban and rural areas have integrated the coordinated development of urban and rural areas, using cities to lead rural areas and replacing small ones with large ones, focusing on the construction of large water sources, water plants and pipe networks [3]. The centralized water supply model usually involves large water plants and long-distance water transmission networks, and is suitable for densely populated areas. It has the advantages of high management level, reliable water quantity and quality, high water supply guarantee rate, long project sustainable period and low per capita investment. Tan et al. [4] show that a rural drinking water project in a mountainous area of Zhejiang Province can improve the quality of rural drinking water and meet the water demand of villagers through engineering measures such as expanding the existing water plant, changing the water source pattern, and choosing a centralized water supply mode. Centralized water supply has advantages in water quality control and management, but the implementation cost is higher in remote mountainous areas. According to studies like [5], some villages are irrigated with unified water sources, but the irrigation water sources in most areas are scattered. The water price in the unified water source area is low, while the water price in the dispersed water source area is high. In contrast, decentralized water supply mode (such as small water plants and rainwater collection systems) is more feasible in rural areas with limited resources, but the quality and quantity of water are sometimes unstable, and decentralized water supply plays a positive role in improving local water resource utilization efficiency. Ma et al. [6] found that water cellar, as a storage method for decentralized water supply, solves the problem of uneven spatial and temporal distribution of rainfall. In general, decentralized systems are more suitable for reuse purposes that require lower quality standards, because the point of use of the reused water is the same as the point where the wastewater is generated, thus avoiding the need for two deliveries to the wastewater plant and back [7]. Conversely, when high quality treated wastewater is required, centralized systems are preferred because of the complex treatment required.

In rural water supply system, water quality safety is one of the key problems. According to preliminary investigations, more than 300 million people in villages and towns across the country have unsafe drinking water, and about 190 million people have excessive levels of harmful substances in drinking water [8]. Scholars have developed a variety of water treatment technologies suitable for rural areas, such as solar water treatment, membrane filtration technology and biological purification technology. These technologies have attracted attention because of their low cost and ease of operation. For example, the solar sterilization technology developed by Li et al. and applied in some areas [9] is one of the effective ways to alleviate the shortage of fresh water resources, showing good water quality improvement effects. With the development of the Internet of Things and big data technology, smart water supply systems are gradually being promoted in rural areas. Relevant studies have shown [10] that intelligent water supply management can significantly improve water supply efficiency and reduce operating costs. The introduction of intelligent water supply system into the management of rural drinking water safety projects can effectively overcome the disadvantages of scattered distribution of rural water conservancy facilities, difficult operation and maintenance management, and substandard water quality, and effectively ensure the safety of drinking water in rural areas. These systems can effectively warn of water shortages and pollution by monitoring water quality and quantity in real time.

Effective management mechanism cannot be separated from perfect policy support. Domestic and foreign scholars have stressed that the government should strengthen policy guidance for rural water supply systems [11] and ensure the rational use of water resources through laws and regulations. For example, some countries have enacted water resources management laws [12] to clarify the responsibilities of governments at all levels in water supply. In addition, the economic self-sufficiency of the system is ensured through the establishment of a water supply fee collection mechanism. G et al. [13] pointed out that the sustainable development of rural water supply systems requires reasonable financial management and investment mechanisms. In addition, the government's financial subsidies and the introduction of social capital are also effective ways to improve the sustainability of water supply systems. Training and capacity-building of managers are critical in rural water supply management. Studies have shown that professional training for managers can improve their capabilities in technical operation, equipment maintenance and emergency management, thereby enhancing the overall operational efficiency of the water supply system [14].

At present, most studies on rural drinking water focus on a specific technology or a regional water supply management model, but there are relatively few studies involving the development of drinking water sources in villages and towns, the improvement of water quality, and the comprehensive system of drinking water safety guarantee technology and operation management.

ISSN 2616-5872 Vol.6, Issue 6: 19-25, DOI: 10.25236/AJEE.2024.060603

This study carried out the whole process of improving the technical level and management ability of drinking water in villages and towns in China from the source to the leading, and formed a complete set of water supply mode, technology and management comprehensive solutions for villages and towns, providing scientific support for improving the level of water supply security in villages and towns in China in the future.

2. Selection and implementation of water supply mode in villages and towns

China's natural conditions are complex and diverse, and the economic and social development levels of villages and towns are different. The water supply mode mainly includes the following three forms: (1) Integrated urban and rural water supply: by expanding the scale and scope of water supply in cities and central villages and towns, the pipe network is laid to the countryside, and the centralized water supply system is formed to realize the integration of rural water supply, and the rural water supply is the same network, the same quality and the same management; (2) Centralized water supply in towns and villages: small and medium-sized water plants are built in towns or villages, while radiating to the surrounding areas; (3) Single village distributed water supply: For remote areas, high altitude and cold areas, the use of single village to build decentralized water supply facilities, simultaneous supporting purification and disinfection processes. Under each water supply model, according to the main body of construction management, ownership and management rights and benefit range, it is subdivided into multiple models and types. There are many modes of operation and management of rural water supply projects, and the selection of modes should fully consider the influence of local geographical characteristics, water resources, local economic development, future development planning of villages and towns and other factors:

a. The influence of geographical features. In the selection of management mode of rural water supply projects, local geographical characteristics should be mainly considered. Geomorphological characteristics such as plain, mountain, hill or desert determine the degree of resident dispersion and water supply mode of villagers in the area, and also determine the water supply cost and scale of rural water supply projects. We should fully consider the elevation distribution of residents, population distribution and water source characteristics to choose the appropriate operation and management mode.

b. Influence of water resources status. The water quality, quantity and carrying capacity of the source are also important reference factors for the selection of rural water supply project mode. The surface water source with good water quality and abundant water quantity, which does not affect the original function after mining, or does not cause the continuous decline of groundwater level, the deterioration of water quality or the ground settlement, can be used as the water source of large and medium-sized rural centralized water supply projects, and the residential area is too scattered and the water quality is good, can also choose high water tank for small-scale or single household water supply. If the water quality and quantity of the source cannot meet the requirements, it is necessary to replace or increase the water source and increase the regulation and storage project.

c. The impact of local economic development. The capital investment of rural water supply projects determines the subsequent planning and development, and the level of local economic development determines the mode selection of rural water supply projects. Economically underdeveloped areas should also consider the affordability of water prices for residents. Local governments should make full use of existing facilities and maximize the benefits of centralized water supply projects. The selection of water supply modes should be diversified, and centralized water supply projects with certain benefits can be managed by professional companies.

d. Influence of future development planning of villages and towns. The construction of rural water supply projects should consider the overall development plan of local villages and towns, development needs and regional economic structure, and put forward the scale and quality requirements of rural water supply. Long-term consideration should be given to the development and construction of local water supply undertakings, and the implementation should be promoted in a planned and step-by-step manner.

3. Key technologies and applications of water supply in villages and towns

The key technologies and applications of water supply in villages and towns are shown in the Table 1.

ISSN 2616-5872 Vol.6, Issue 6: 19-25, DOI: 10.25236/AJEE.2024.060603

Table 1: Key technologies and applications

Technology	Usage characteristics	Problem characteristics	Main content	Application situation
Conventional process intelligent technology	The conventional technology village water plant with surface water and groundwater as water source	Determine the reasonable dosage of coagulant	The data were used to construct an algorithm model for water quality feedback adjustment	Xi 'an, Shaanxi Province, Changan District Qingbo water plant construction disinfection intelligent operation equipment demonstration project 1
Study on deep removal of manganese by adsorption-autocatalytic oxidation	Groundwater source	The problem of high manganese ion content in drinking water in villages and towns	Rapid sand filter (RSF) process for manganese removal was developed	Heilongjiang, province, Suihua City, Lanxi county, Fendou township
One step arsenic removal technique of "synergistic oxidation - adsorption filtration"	Arsenic (As) concentration ranges from 10 to 200μg/L in primary arsenic groundwater and arsenic wastewater from coal mines	High arsenic groundwater in villages and towns	Composite metal oxide arsenic removal materials based on iron (Fe) and manganese (Mn) oxides capture pentavalent arsenic in water through adsorption/condensation process (As(V))	A village in Zhouzhi County, Xi 'an City, Shaanxi province
Antimony removal by flocculation	The heavy metal antimony slightly polluted the water source	It solves the technical problem that traditional flocculants can only effectively flocculate antimony removal under acid corrosion conditions. The problems such as poor water force condition, long residence time and mud accumulation in the conventional grid flocculation tank are solved	A new type of composite flocculant was synthesized at room temperature to form a floc with metal and metal oxide particles, and the antimony was removed by rapid sedimentation	Hunan Yiyang City water Supply Co., LTD. (four water plant) of Hunan University practice teaching base
Drinking water complex adsorption defluorination technology	For water sources with excessive fluoride in groundwater or surface water, it is suitable for distributed rural water supply or urban water supply plants below 10,000 tons	The capacity of defluorinated adsorbent in rural water supply is low and the regeneration is difficult	In situ loading or in situ preparation contact filtration enables the combination of adsorption and solid-liquid separation processes	The demonstration project of fluoride removal in Inner Mongolia is located in Shahai Town, Hangjin Houqi, Bayannur City

ISSN 2616-5872 Vol.6, Issue 6: 19-25, DOI: 10.25236/AJEE.2024.060603

4. Study on long-term management mechanism of water supply in villages and towns

Due to the abundant rainfall of mountainous cities in the south, water supply for villages and towns is prone to problems such as excessive heavy metals and E. coli [15], resulting in drinking water safety problems. Water intake is difficult in deep mountainous areas, and seasonal water shortage in shallow hilly areas is serious, which belongs to engineering water shortage [8]. Water supply zones should be demarcated according to the characteristics of terrain, water resources, population and industrial distribution. In northern China, water resources are relatively scarce, seasonal water shortage is serious, and neither surface water nor groundwater can be found. Therefore, attention should be paid to the promotion and application of water-saving technologies, such as drip irrigation, sprinkler irrigation and other efficient irrigation technologies [16]. Promote sewage treatment and the reuse of reclaimed water to ease the shortage of water resources.

4.1. Urban and rural water supply integration project in Shanyang County

Shanyang County is located in the southeast of Shangluo City, the previous water supply projects in this area are relatively scattered, water supply standards are not unified, it is difficult to achieve centralized management. At the same time, the operation and monitoring of water supply facilities are less automated. At present, the county uses the existing surface water as the main source of water supply, and new water treatment plants to improve the safety and quality of water supply and promote the modernization of water supply. All newly built water intake hubs adopt the water intake mode of infiltration canal + collecting well and gravity art-flow water transmission. After purification and treatment, raw water supplies water to the high water tank of each administrative village in the water supply area along the road (trench). At the crossing of the pipeline, the current traffic bridge is used to hang the pipe [17]. Through the construction of water purification measures and centralized water supply, improving the quality and quantity of water used by residents in villages and towns along the river, solving the problem of drinking water quality safety and water quantity guarantee, has important social significance for improving residents' happiness of life and realizing people's yearning for a better life.

4.2. Shaanxi coordinated the construction of water plant pipe network

Caijiapo Town in Shaanxi Province is located in the west of Guanzhong Plain. According to incomplete statistics, the leakage rate of the water supply pipeline in Caijiapo is as high as 21%[18]. Some pipe networks are seriously aging, and various indicators in the water have increased, resulting in secondary pollution of the water quality, and the safety cannot be guaranteed. The small town water supply system lacks scientific management methods, low management level and poor economic benefits, which affects the improvement and development of the whole town water supply system. Therefore, according to the "urbanization of rural water supply, integration of urban and rural water supply, integration of construction funds and investment, infrastructure layout needs to match urban development, funds to guarantee urban water supply construction, and strive for government support." Systematic transformation of the water supply network and facilities in the old city, following the principle of "overall planning, focus, step by step, and capacity", scientific planning and implementation, and preparation.

4.3. Digital management of water supply project in Rongchang District

Rongchang District belongs to Chongqing, located at the junction of Chongqing and Sichuan, is the gateway to the west of Chongqing, and also the emerging strategic fulcrum of Chengdu-Chongqing economic circle. The rural tap water in Rongchang District cannot achieve full coverage, the operation and management is difficult, the drinking water safety risks exist, the water supply scale is small, the supply is insufficient, and the water pollution is serious, so the government departments should strengthen the construction and management of rural water supply projects. Currently, there are 29 rural water supply projects completed and put into use in Rongchang District, with a water supply rate of 92.03%[19]. In order to continuously improve the quality of water supply, the district is gradually updating and transforming water production equipment, planning and building rural sewage and garbage treatment facilities, and rationally distributing environmental infrastructure such as sewage treatment facilities, harmless household garbage treatment sites and garbage transfer stations. At the same time, supporting the construction of sewage collection network and garbage collection and transportation, in order to reduce the pollution of domestic garbage to the water source. In addition, the district is also committed to ensuring the quality of domestic water for rural residents and the amount of water supplied,

ISSN 2616-5872 Vol.6, Issue 6: 19-25, DOI: 10.25236/AJEE.2024.060603

and further strengthening the work of water quality assurance. To this end, strengthen the supervision of water resources, improve the monitoring network of rural water sources, scientifically and reasonably determine the water quality measurement index and frequency, and do a good job in daily water quality testing of water sources, in order to improve the safety management of domestic water use for rural residents. We will innovate rural water supply management models, encourage qualified districts and counties to actively integrate urban and rural water supply, extend urban water supply networks to surrounding rural areas, and promote urban and rural water supply networks with the same water quality and services. Rongchang District strives to achieve safe and healthy drinking water in rural areas through the above efforts.

4.4. Regional water supply in Changhai County

The terrain of Xiaochangshan Island is mainly hilly, with typical features of northern islands. Based on factors such as terrain characteristics and water demand of Xiaochangshan Island, a zonal water supply system is adopted to achieve relatively independent water supply in the east, west and middle regions [20], which is conducive to the safe operation of the water transmission and distribution network and plays an energy-saving role. The implementation of the water supply project in Xiaochangshandao Town will comprehensively solve the drinking water problem of residents in Xiaochangshandao Town, improve the local investment environment, accelerate the construction of infrastructure, and thus drive and accelerate the development of local social economy.

5. Conclusion

To construct a water supply model and long-term management mechanism that adapt to the characteristics of Chinese villages and towns, it is necessary to comprehensively consider many factors such as technological innovation, policy support and public participation. Future studies can further explore successful cases in different regions, form experiences that can be generalized, and provide more systematic theoretical support and practical guidance for water supply management in China.

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