DOI 10.15302/J-SSCAE-2018.05.011

Irrigation with Unconventional Water Resources in China: Review and Development Strategy

Hu Yaqi[1, 2], Wu Wenyong[1, 2]

1. State Key Laboratory of Simulation and Regulation of Water Cycles in River Basins, China Institute of Water Resources and Hydropower research, Beijing 100038, China
2. Department of Irrigation and Drainage, China Institute of Water Resources and Hydropower research, Beijing 100048, China

Abstract: With the increasing shortage of water resources, the development and utilization of unconventional water resources have received increasing attention from various countries. Using unconventional water resources for irrigation is an important measure for dealing with the shortage of water resources, and this strategy mainly involves reclaimed water and brackish water. In China, agricultural unconventional water resources have relatively high potential. It has been predicted that the amount of unconventional water available for agriculture will reach 3.438×10^{10} m^3 in 2030, while the amounts of reclaimed water and brackish water required for irrigation will reach 1.645×10^{10} m^3 and 2.48×10^9 m^3, respectively. In areas where fresh water resources are lacking and unconventional water resources are relatively abundant, especially in the northern arid regions, developing and using unconventional water resources can be regarded as viable solutions for addressing the shortage of fresh water. Based on the situation in China, this study provides a summary of irrigation modes using unconventional water resources. From the aspects of zoning technology, suitable crop classification, pollution identification technology, high-efficiency irrigation techniques, monitoring and evaluation technology, and integrated application modes, this paper proposes safe irrigation measures for unconventional water resources in China. Finally, to establish a technical system for unconventional water resources utilization suitable for China's agricultural sector, this paper recommends a development and utilization strategy. This strategy aims to strengthen technical research into and popularization of agricultural unconventional water resources utilization technology, improve the recycling standards and regulation system, introduce unconventional water resources into water resources development and utilization planning, and formulate incentive policies.
Keywords: unconventional water resources; reclaimed water; brackish water; irrigation

1 Introduction

With the fast rate of social and economic development and the rapid increase in population, the water resource conflict between supply and demand has become increasingly obvious. China's water resources are scarce, amounting to only 2100 m^3 per capita, which is less than one-third of the world average, ranking the country as 127th in the world [1]. Because each region is located within different hydrological belts and is influenced by a monsoon climate, the temporal and spatial distribution of freshwater resources is uneven in China. Furthermore,

Received date: August 20, 2018; **Revised date:** August 30, 2018
Corresponding author: Wu Wenyong, China Institute of Water Resources and Hydropower research, professorate senior engineer. Main research field is basic theories and techniques in agricultural water-saving. E-mail: wenyongwu@126.com
Funding program: National Key R&D Program of China "Technology and Methods for Optimal Dispatching and Allocation of Irrigational Multi-Water Resources" (2016YFC0400102); CAE Advisory Project "Research on Key Strategic Issues of Agricultural Resource and Environment in China" (2016-ZD-10).
Chinese version: Strategic Study of CAE 2018, 20 (5): 069–076
Cited item: Hu Yaqi et al. Irrigation with Unconventional Water Resources in China: Review and Development Strategy. *Strategic Study of CAE*, https://doi.org/10.15302/J-SSCAE-2018.05.011

uneven distribution of cultivated land resources, low water utilization efficiency, and severe water pollution have exacerbated the fresh water resource crisis. China is a large agricultural country, and this sector is the biggest consumer of water, accounting for approximately 65% of total water consumption. The vast majority, namely 90%, of the agricultural water consumption is used for irrigation. Thus, agricultural development is likely to become the first serious casualty of the increasingly limited conventional water resources. Developing and using unconventional water resources via multiple channels results in sustainable utilization of these resources, and thus, this topic has received growing attention in various countries, including China. It is extremely important to alleviate the issues surrounding agricultural water resources. Unconventional water resources primarily include reclaimed water, brackish water, rainwater, and seawater, of which reclaimed water and brackish water are mainly used in agriculture. Specifically, reclaimed water refers to the useful water obtained from sewage through proper treatment, and after processing, a certain water quality standard is achieved and specific functional requirements are met [2]. Brackish water generally refers to brine with a salinity of 2−5 g/L [3]. In agricultural irrigation, the reasonable development and utilization of unconventional water resources not only increases irrigation water resources, but also ensures meeting the irrigation rate requirements. Thus, the use of unconventional water resources is considered to be an important measure for alleviating water resource shortages [4,5]. This article briefly introduces the distribution characteristics and agricultural utilization status of unconventional water resources in China, the modes and safeguard measures for safe irrigation, as well as the future development trends. The goal of this study is to provide a reference for the utilization of unconventional water resources in the agricultural sector in China.

2 Evaluation of unconventional water resources utilization in China's agriculture sector

2.1 Distribution of unconventional water resources utilization in China's agriculture sector

China has a large quantity of unconventional water resources. For example, in 2015, the volume of water used in field irrigation amounted to 3.377×10^{11} m^3 [6]. According to investigations and data analyses, in 2015, the volume of reclaimed water nationwide was 3.665×10^{10} m^3 and that used in field irrigation was 1.101×10^{10} m^3. The irrigated areas using the maximum reclaimed water resources comprised North China, with 5.21×10^9 m^3, and the Yangtze River area, with 2.57×10^9 m^3. The natural recharge of brackish water (of salinity 2−5 g/L) was 2.459×10^{10} m^3, and the exploitable volume of brackish water was 8.78×10^9 m^3, which was mainly distributed in the North China Plain, the Songliao Plain, the Loess area in the middle reaches of the Yellow River, the arid area of Northwest China, and the coastal areas of the Yangtze River Delta. The irrigation volume of brackish water amounted to 1.48×10^9 m^3, and the areas irrigated with the maximum brackish water volume comprised North China with 9.3×10^8 m^3 and the Loess plateau (including the Shanxi, Shaanxi, and Gansu provinces), with 4.2×10^8 m^3. The distribution of the volume of agricultural unconventional water resources for each district in 2015 is shown in Table 1.

Table 1. Agricultural unconventional water resources volume in various districts in 2015 ($\times 10^8$ m^3).

Regional division	Reclaimed water		Brackish water		
	Reclaimed water resource volume	Farm irrigation volume	Natural recharge	Exploitable volume	Farm irrigation volume
Northeast China	30.2	13.1	0.0	0.0	0.0
North China	77.8	52.1	43.0	28.0	9.3
Yangtze River area	123.3	25.7	53.6	38.3	0.5
South China	78.1	6.8	4.7	3.1	0.0
Meng-Ning	6.8	3.0	9.5	5.7	0.8
Jin-Shaan-Gan	14.4	5.6	28.0	11.0	4.2
Chuan-Yu	18.9	0.9	0.0	0.0	0.0
Yun-Gui	11.1	0.5	5.2	0.0	0.0
Qing-Zang	1.2	0.0	102.2	1.7	0.0
Northwest China	4.7	2.3	0.0	0.0	0.0
Whole country	366.5	110.1	245.9	87.8	14.8

2.2 Status and potential for unconventional water resources utilization in China's agriculture sector

The potential for developing and utilizing unconventional water resources in China is enormous, and research on these aspects is of great significance for promoting water resources, water ecology, and the carrying capacity of the aqueous environment, as well as facilitating the spatial balance. Since the beginning of the large-scale use of sewage

DOI 10.15302/J-SSCAE-2018.05.011

irrigation in China in the 1950s, five largest sewage irrigation areas were successively formed nationwide including Beijing, Tianjin Wubaoning, Liaoning Shenfu, Shanxi Huiming, and Xinjiang Shihezi [7]. By 1991, the size of the national sewage irrigation area reached 3.067 × 10^6 hm^2 [8]. After the year 2000, the agricultural water shortage situation became serious, and the utilization of reclaimed water for irrigation received widespread attention. Beijing established several reclaimed water irrigation areas (e.g., in Xinhe and Nanhongmen) and these came to be known as the largest irrigation areas in China. The irrigation area exceeded 6 × 10^5 mu (one mu equals approximately 666.667 m^2), and in 2010, the reclaimed irrigation volume was 3 × 10^8 m^3 [9]. By 2015, the reclaimed water irrigation volume nationwide reached 1.101 × 10^{10} m^3. In Beijing, Tianjin, Inner Mongolia, Shaanxi, Shanxi, and other provinces and autonomous regions, large-scale promotion and utilization of reclaimed water has been achieved for field irrigation, greenbelt irrigation, and supplementing water for landscaping. To promote the utilization of reclaimed water irrigation, the standard titled *The Reuse of Urban Recycling Water—Quality of Farmland Irrigation Water* (GB 20922—2007) was promulgated [10]. Local standards for reclaimed water irrigation engineering were also established in Beijing and other areas, such as the Inner Mongolia autonomous region. The above works promoted the widespread use of reclaimed water.

In China, brackish water is widely distributed and available in large quantities. This is especially true of North China, Northwest China, and the coastal areas, especially in saline soil zones. The majority of brackish water is located 10−100 m below the ground, which is relatively easy to develop and utilize [11]. The practice of using brackish water to irrigate farmlands has a long history in China, but research on brackish water only began sometime in the 1960s and 1970s. Ningxia was the first to use brackish water for farmland irrigation, and barley and wheat production increased due to irrigation with this water resource compared to growing these crops on rainfed cropland. Tianjin proposed using brackish water with a salinity of 3−5 g/L for irrigation, which was in accordance with the quality safety regulations for arid farmlands [12]. In Hengshui, brackish water was used for irrigation, leading to savings of 1 × 10^8 m^3 of groundwater and 40 million CNY in costs [13]. Additionally, Inner Mongolia, Gansu, Henan, Shandong, Liaoning, and Xinjiang have reported many productive practical irrigation experiences with brackish water in varying degrees, and greater crop productivity was achieved. At present, areas such as the Haihe River basin, western Jilin, central Inner Mongolia, and Xinjiang, mainly utilize brackish water. The natural recharge of underground brackish water with a salinity of 2−5 g/L is 2.459 × 10^{10} m^3, and the irrigation volume of brackish water is approximately 1.48 × 10^9 m^3.

In China, agricultural unconventional water resources have relatively high potential. It has been predicted that by the year 2030, the amount of unconventional water resources available for agriculture will reach 2.951 × 10^{10} m^3, with the irrigation volume of reclaimed water being 1.645 × 10^{10} m^3 (5.44 × 10^9 m^3 more than in 2015) and that of brackish water being 4.87 × 10^9 m^3 (1 × 10^9 m^3 more than in 2015). In areas where fresh water resources are lacking and unconventional water resources are relatively abundant, especially in the northern arid regions, developing and using unconventional water resources can be regarded as a good solution for addressing the shortage of local fresh water resources.

3 Irrigation technology modes using agricultural unconventional water resources

3.1 Irrigation technology modes using reclaimed water

Many practical reclaimed water treatment technologies have been developed in China and abroad. The Werribee farm in Melbourne, Australia applied percolation treatment to sewage using land infiltration, surface seepage, and oxidation ponds. The Nanhongmen reclaimed water irrigation area in Daxing District, Beijing, used the Yanggezhuang wetland (i.e., pond treatment) as well as seasonal regulation and storage of reclaimed water to increase the utilization efficiency of reclaimed water. A deep land treatment system and a wetland treatment system with properly planned irrigation methods and schedules facilitate the use of reclaimed water for growing all crop types and garden plants [14]. In general, depending on the composition of the pretreatment process in the reclaimed water irrigation system, the reclaimed irrigation mode can be divided into four types, that is, “4R” modes (Table 2). They are as follows. (1) The SR mode, wherein the secondary effluent is purified by the Soil Aquifer Treatment (SAT) System and is then used for irrigation; (2) the WR mode, in which the secondary effluent is purified by the Wetland Treatment System (WTS) and then used for irrigation; (3) the CR mode, in which the secondary effluent is diluted by the natural water cycle and then used for irrigation; and (4) the DR mode, wherein the deeply purified effluent is directly used for irrigation. Additionally, the safe irrigation technology using reclaimed water also considers the identification of plant types, risk assessment, pollution control, and use of spray-drop irrigation technology.

Table 2. “4R” modes of reclaimed water irrigation.

Items	SR mode	WR mode	CR mode	DR mode
Mode description	The soil aquifer treatment system (SAT) is used as a pretreatment facility to purify the reclaimed water, and the effluent enters the irrigation water distribution pipeline.	The wetland treatment system (WTS) is used as a pretreatment facility to purify the reclaimed water, and the effluent enters the irrigation water distribution pipeline.	The secondary treatment effluent from the sewage treatment plant complies with the standard and enters the landscaping water in the upper reaches of the river and lake system through downstream self-flow purification. This water is used for irrigation.	The purified effluent is transported to the regulating pond system and then enters the irrigation network system, which is used for field irrigation.
Water quality requirement	Secondary treatment effluent and above			Tertiary treatment effluent
Crop type	Any crop	Any crop (except for raw vegetables, herbs, and fruits)	Any crop (except for raw vegetables, herbs, and fruits)	Any crop
Irrigation method	Spray-drop irrigation	Surface irrigation and spray-drop irrigation	Surface irrigation and spray-drop irrigation	Spray-drop irrigation

3.2 Irrigation technology modes using brackish water

During production, various countries in the world adopt different technologies when using brackish water for irrigation depending on the circumstances at hand. Wang et al. [15] demonstrated that direct use of brackish water with a salinity of less than 3 g/L to irrigate spring corn for three consecutive years did not cause any obvious reduction in yield. Lin et al. [16] found that using the mixed irrigation mode (i.e., salt and fresh water) was most beneficial for cucumber yield as well as quality. In general, the brackish water irrigation technology includes three categories, or “3I” modes, namely, direct irrigation with brackish water (DI), mixing irrigation with saline and fresh water (MI), and alternating irrigation with saline and fresh water (AI) (Table 3). The DI mode is mainly used in areas where land permeability is optimal, fresh water resources are lacking, and the plants chosen for planting are salt-tolerant [17,18]. The MI mode involves the mixing of fresh and salt water, and irrigation is carried out by diluting the brine [19]. For crops sensitive to salinity at the seedling stage, alternating irrigation with saline and fresh water (AI) can be adopted [20]. Salt water irrigation is mainly applied to salt-tolerant and drought-resistant crops. The irrigation volume and irrigation frequency should be reasonably controlled to allow for the selection of a proper irrigation mode. This is possible after carefully considering factors such as crop quality, water quality, soil type, climatic conditions, groundwater depth, and the corresponding agronomic measures, as well as a combination of irrigation methods (surface irrigation and spray-drop irrigation).

Table 3. “3I” modes of brackish water irrigation.

Items	Direct irrigation mode using brackish water (DI)	Mixed irrigation mode using salt and fresh water (MI)	Alternate irrigation mode using salt and fresh water (AI)
Mode description	The exploited brackish water is directly irrigated into the field.	Depending on its salinity, the salt water is mixed with a corresponding proportion of fresh water, such that the mixed water meets the standard for irrigation water quality and can irrigate all crops.	Depending on the sensitivity of the crop’s growth period to salinity, fresh water irrigation is adopted during the salt-sensitive period of the crops, and salt water irrigation is used during the non-sensitive period.
Crop type	Salt-tolerant plants	Relatively extensive	Salt-sensitive crops
Soil requirement	Good soil permeability	Agronomic measures, good soil permeability	Agronomic measures should be combined

DOI 10.15302/J-SSCAE-2018.05.011

Table 3 (*continued*)

Items	Direct irrigation mode using brackish water (DI)	Mixed irrigation mode using salt and fresh water (MI)	Alternate irrigation mode using salt and fresh water (AI)
Irrigation method	Surface irrigation and spray-drop irrigation	Surface irrigation and spray-drop irrigation	Surface irrigation and spray-drop irrigation

4 Safeguard measures for irrigation with unconventional water resources

The utilization of unconventional water resources, such as reclaimed water and brackish water, in China's agricultural sector shows relatively high potential. It is necessary to facilitate safe and high-efficiency utilization of unconventional water resources with regard to the following six aspects: unconventional agricultural water irrigation, suitable crop classification, pollution identification technology, high-efficiency irrigation techniques, monitoring and evaluation technology, and integrated application modes. Thus, technological improvements are required to meet the applicable technical specifications.

4.1 Irrigation zoning technology

Irrigation zoning technology is very important for the utilization of unconventional water resources. Reclaimed water irrigation should be used to focus on the prevention of associated pollution, and brackish water irrigation should mainly prevent and control secondary salinization of the soil. Irrigation zoning technology divides the reuse area, and the safety and utilization efficiency of unconventional water resources are improved.

Zoning for reclaimed water irrigation is an important measure to ensure the safe utilization of reclaimed water. The irrigation suitability zoning of reclaimed water irrigation areas should be based on the physical and chemical properties of the soil, soil quality, groundwater depth, surface slope, etc. Zoning of reclaimed water irrigation should be carried out according to Table 4.

Table 4. Suitable zoning standard for reclaimed water irrigation.

Type	Control index		
	Groundwater depth D (m)	Permeability coefficient of aeration zone K (m/d)	Ground slope I (%)
Suitable irrigation district	$D \geq 8.0$	$K < 0.5$	$I < 2.0$
Control irrigation district	$3.0 \leq D < 8.0$	$0.5 \leq K < 0.8$	$2.0 \leq I < 6.0$
Unsuitable irrigation district	$D < 3.0$	$K \geq 0.8$	$I \geq 6.0$

Brackish water irrigation areas generally have good drainage conditions, and when combined with a suitable irrigation system and management mode, salt accumulation in the root layer soil can be effectively controlled. Areas where the soluble sodium percentage (SSP) in the soil is less than 65% and the sodium adsorption ratio (SAR) is less than or equal to 10 are suitable for brackish water irrigation [21]. The suitability zoning of brackish water irrigation should be based on factors such as the irrigation area's climate, water quality of the brackish water, groundwater depth, and soil texture type (Table 5).

Table 5. Suitability zoning standard for brackish water irrigation.

Salinity	Soil type	NAW[a]								WAW[b]	SAW[c]
		$R^d < 200$			$200 \leq R \leq 800$			$R > 800$			
		$D^e < 3.0$	$3.0 \leq D \leq 6.0$	$D > 6.0$	$D < 1.5$	$1.5 \leq D \leq 3.0$	$D > 3.0$	$D < 1.5$	$D \geq 1.5$		
Mild saline water 1−2 g/L	Sand	×[h]	Δ	✓[f]	Δ[g]	✓	✓	Δ	✓	✓	×
	Loam	×	Δ	✓	×	Δ	✓	Δ	✓	Δ	×
	Clay	×	×	Δ	×	×	Δ	×	Δ	Δ	×
Moderate saline water 2−3 g/L	Sand	×	Δ	✓	Δ	✓	✓	Δ	✓	✓	×
	Loam	×	Δ	✓	×	Δ	✓	Δ	✓	Δ	×
	Clay	×	×	Δ	×	×	Δ	×	Δ	×	×
Severe saline water 3−5 g/L	Sand	×	×	Δ	×	Δ	✓	Δ	✓	✓	×
	Loam	×	×	Δ	×	×	✓	Δ	✓	Δ	×
	Clay	×	×	×	×	×	×	×	×	×	×

[a]Non-alkaline water.

[b]Weakly alkaline water
[c]Strongly alkaline water
[d]Rainfall (mm)
[e]Groundwater depth (m)
[f] Suitable irrigation district
[g]Control irrigation district
[h] Unsuitable irrigation district

4.2 Suitable crop classification

Crops are classified for reclaimed water irrigation as follows. (1) Plants used as industrial raw materials, gardens/greenbelts, and trees receive preference; (2) grain crops, vegetables that require cooking or peeling, melons, fruit trees, pastures, and feed classes are recommended for reclaimed water irrigation; and (3) vegetables that are eaten raw and herbaceous fruits are not recommended for reclaimed water irrigation [10].

Crops are classified for brackish water irrigation as follows. (1) Medium or severe brackish water can be used to irrigate extremely salt-tolerant plants; (2) light or medium brackish water can be used to irrigate medium-level salt-tolerant plants, and severe brackish water can be used to irrigate areas with good drainage salt control conditions, namely, with a leaching fraction LF $\geq$ 36%; (3) light brackish water can be used to irrigate the medium-level salt-sensitive plants, and severe brackish water cannot be used to irrigate areas where the drainage and salt control conditions are suitable, namely, with LF $\geq$ 50%; and (4) medium or severe brackish water cannot be used to irrigate salt-sensitive plants in irrigation areas where drainage salt control conditions are suitable, namely, with LF $\geq$ 80%.

The salt tolerance abilities of different plants are shown in Table 6 [22].

Table 6. Classification of salt tolerance in plants.

Salt tolerance grade	Plant type	Salt-tolerant threshold EC_e (dS/m)
Salt-tolerant	Barley, beet, cotton, asparagus, etc.	$6.0 \leq EC_e < 10.0$
Medium-level salt-tolerant	Wheat, oat, rye, sorghum, soybean, cowpea, safflower, alfalfa, oilseed grape, sunflower oil, pumpkin, pomegranate, fig, olive, pineapple, sunflower, etc.	$3.0 \leq EC_e < 6.0$
Medium-level salt-sensitive	Corn, flax, chestnut, peanut, rice, sugarcane, cabbage, celery, cucumber, eggplant, lettuce, muskmelon, pepper, potato, tomato, radish, spinach, watermelon, grape, etc.	$1.3 \leq EC_e < 3.0$
Salt-sensitive	Kidney bean, sesame, carrot, onion, pear, apple, orange, plum, apricot, peach, strawberry, etc.	$EC_e < 1.3$

4.3 Risk assessment technology

Improving risk assessment technology is an important technical aspect of promoting the safe utilization of agricultural unconventional water resources in irrigation. Through this analysis, the current risk of the development and utilization of unconventional water resources can be quantitatively characterized, and the evolution in environmental trends for the targeted years of irrigation can be predicted. The following factors are focused upon: (1) Evaluation objects: the environmental quality of the soil, crops, groundwater, and public health; (2) Evaluation method: the risk assessment method is mainly based on a combination of experimental research and numerical simulations, and determining the manner of evaluation of the risk of reclaimed water utilization under compounding pollution conditions is a challenge that requires further study in the future; and (3) Evaluation threshold: this threshold is set according to different reuse targets, to establish the corresponding threshold index system as a basis for the risk assessment. Presently, China has made progress with respect to studying the evaluation methods of unconventional water resources. However, the risk evaluation of the impacts of persistent emerging contaminants in reclaimed water is in its nascent stages, both in China and abroad. Therefore, further research is required. Establishing a method for the health risk assessment of emerging contaminants when using reclaimed water for irrigation is the technical bottleneck for the safe utilization of existing reclaimed water.

4.4 Efficient irrigation technology

The high-efficiency utilization technology using agricultural unconventional water resources includes irrigation technology and an irrigation system. To apply such technology to agricultural reclaimed water, technological

DOI 10.15302/J-SSCAE-2018.05.011

breakthroughs are necessary at the regional and field scales. At the regional level, issues related to the optimal operation of water resources in large-/medium-sized reclaimed water irrigation areas need to be solved. At the field scale, to improve the uniformity of irrigation and service life of the equipment, the influencing mechanism of suspended solids on spray-drop irrigation systems, as well as improvements to the technique during the process of reclaiming water should be addressed. To apply high-efficiency utilization technology to agricultural brackish water, a safe and high-efficiency irrigation system should be established. It is also necessary to propose a water-manure-salt coupling simulation model for brackish water irrigation, and to establish an irrigation system that can adjust and control water-salt optimization for the micro-irrigation of brackish water.

4.5 Monitoring and evaluation technology

A monitoring and evaluation system should be established for the development and utilization of agricultural unconventional water resources, so as to quantitatively evaluate the evolution process of environmental quality. The following three elements are necessary. (1) A monitoring indicator: depending on the influencing mechanism of unconventional water resources irrigation on environmental factors, such as soil, crops, and groundwater, the corresponding physical, chemical, and biological indicators are screened as annual monitoring indicators; (2) The monitoring of density and frequency: according to the spatial-temporal variability and geostatistical characteristics of the main monitoring pollutant indicators, the calculation method for monitoring density and frequency can be established; and (3) An evaluation method: it is necessary to investigate and establish single factor and comprehensive evaluation methods, and to define their applicable conditions.

4.6 Integrated application mode

Development of key technologies for reclaimed water irrigation and brackish water irrigation, as well as their integrated technical application is crucial with regard to promoting the popularization and application of agricultural unconventional water resources. First, the engineering structure and scale of the typical irrigation mode should be proposed, the planning design method of agricultural unconventional water resources irrigation must be established, and the technical parameters for different irrigation works in typical irrigation areas should be defined. Second, a basic system for irrigation operation and management can be developed according to the characteristics of water quality, so as to provide additional benefits from irrigation operation and management. Third, research on the corresponding standards and regulations, as well as the management system, should be conducted to devise integrated applications of unconventional water resources, using a combination of engineering, agronomic, and management measures.

5 Development and utilization strategy for unconventional water resources in China

Compared with the United States, Israel, and other developed countries, the fundamental research, policies, and regulations on the utilization of agricultural unconventional water resources in China are still under development. In order to promote their development and utilization, the following four aspects should be considered on priority.

5.1 Strengthening research and popularization of agricultural unconventional water resources irrigation technology

In China, research on agricultural unconventional water resources utilization commenced relatively late, and thus, a large gap remains between theory and practice compared with developed countries. Research on reclaimed water utilization in China began sometime in the year 2000, and since then, the *National 863 Plan*, *Science and Technology Support Program*, and *Special Research and Development of Water Resources* in the 13th Five Year Plan have included the research topic of developing and utilizing unconventional water resources. In the future, research should focus on pollution identification technology, risk evaluation technology, and high-efficiency irrigation technology for unconventional water resources utilization in agriculture, so as to establish a technical system suitable for China's climate and geographic conditions. Agricultural unconventional water resources development and utilization should be publicized and promoted to the public and farmers, and different types of demonstration areas should be identified to meet this goal.

5.2 Improving standards and regulations for agricultural unconventional water resources reuse

The *China Water-Saving Technology Policy Outline (2005)* clearly proposed that, "…based on the research, to safely use unconventional water, including partial reclaimed water, brackish water, and desalinated seawater, and to increase the agricultural water resources through unconventional approaches such as artificial precipitation technology.” To enact the national policy, it is necessary to formulate technical guidelines for agricultural unconventional water resources utilization. The deficiencies in the technical standard system also serve as a restraining factor. At present, China has formulated the standard titled *The Reuse of Urban Recycling Water—Quality of Farmland Irrigation Water* (GB20922—2007). The water quality standards for brackish water irrigation and the technical specifications for reclaimed water and brackish water irrigation have not yet been formulated. The provincial standard for reclaimed water irrigation has been formulated for Beijing and Inner Mongolia, and the provincial standard for brackish water irrigation has been formulated for Hebei and Inner Mongolia. Other areas, however, have not developed local standards for agricultural unconventional water resources development and utilization. These deficiencies of the standards system objectively restrict the development and utilization of unconventional water resources.

5.3 Allocating unconventional water resources and planning for development and utilization

It is crucial to consider unconventional water resources as part of the total water resources of all administrative regions, so as to ensure uniform allocation and promote unconventional water resources utilization. At present, China does not plan for agricultural unconventional water resources development and utilization, and unconventional water resources still remain to be introduced as part of the total water resources allocation. It is necessary to set goals pertaining to unconventional water resources development and utilization, engineering tasks, and capital inputs in five-year plans for water conservancy development formulated by national and local governments of China, so as to strengthen the development and utilization of agricultural unconventional water resources at the roots. Additionally, policy support such as funding, and reducing or waiving water usage charges, should be provided to projects that develop and utilize unconventional water resources.

5.4 Formulating incentive policies for the development and utilization of unconventional water resources

Scientific pricing of unconventional water resources enables price leveraging to play the leading role in the water resources market. Establishing and perfecting payments for unconventional water resources can supplement the expenses associated with the research, construction, and operation of the equipment. In terms of pricing, subsidies, and tax preference measures, unconventional water resources possess an obvious price advantage and profit opportunities over conventional water resources, which will encourage enterprises to use them. It is necessary to devise comprehensive financial and fiscal policies and systems, and to establish a special support fund to this effect. Enterprises, companies, and research institutions concerned with the development and utilization of unconventional water resources would seek support in terms of tax revenue and project funding. Such enabling measures will promote development and upgradation of utilization technologies using unconventional water resources and its transformation from theory to practice. The advantages of field irrigation should be disseminated among the public so that they can benefit from the development and utilization of unconventional water resources. Government subsidy allocations should be devoted to this area, so as to reduce the development and utilization costs of unconventional water resources, thereby giving this initiative a relative competitive advantage.

6 Conclusions and recommendations

The utilization of agricultural unconventional water resources will effectively alleviate the shortage of regional water resources, especially for China, which possesses enormous potential for the development and utilization of these water resources. It has been predicted that by the year 2030, the irrigation volume of reclaimed water and brackish water will be 1.645×10^{10} m^3 and 2.48×10^9 m^3, respectively, which corresponds to increases of 5.44×10^9 m^3 and 1×10^9 m^3 from 2015. In areas where fresh water resources are lacking and unconventional water resources are relatively abundant, especially the northern arid regions, developing and using unconventional water resources can be regarded as effective solutions for addressing the shortage of local fresh water resources. There are four types of reclaimed water irrigation modes, namely, the SR mode, where secondary effluent is purified by the soil aquifer treatment system and then used for irrigation; the WR mode, where secondary effluent is purified by the wetland treatment system and then used for irrigation; the CR mode, where secondary effluent is improved by the natural water cycle and then used for irrigation; and the DR mode, where the deeply purified effluent is directly used for irrigation. There are three categories of brackish water irrigation technologies, namely, the DI mode of direct irrigation with brackish water, the MI mode of mixing irrigation with saline and fresh water, and the AI mode of

DOI 10.15302/J-SSCAE-2018.05.011

alternating irrigation with saline and fresh water. Appropriate selection of unconventional water irrigation modes can not only increase water supply and crop yield, but also avoid negative impacts on the environment. To promote the safe and high-efficiency utilization of unconventional water resources, technological achievements need to be continuously improved to realize the necessary technical guarantees with regard to six aspects, namely, zoning technology for agricultural unconventional water irrigation, suitable crop classification, pollution identification technology, high-efficiency irrigation techniques, monitoring and evaluation technology, and integrated application modes. However, China's fundamental research, policies, and regulations regarding the utilization of agricultural unconventional water resources are still under development compared with developed countries. According to the country's national circumstances, and based on existing research at home and abroad, it is necessary to further strengthen the technical research and popularization of agricultural unconventional water resources irrigation technology in China, and to improve the system of standards and regulations for agricultural unconventional water resources reuse. It is crucial to introduce unconventional water resources as a part and parcel of planning for agricultural conventional water resources development and utilization, and to formulate incentive policies, so as to establish a technical system of agricultural unconventional water resources utilization suitable for China's climate and national conditions.

Acknowledgements

The study was funded by the National Key Research and Development Program of China (2016YFC0400102) and the Major Consultation Projects of the Chinese Academy of Engineering (2016-ZD-10).

References

[1] Wang H, Wang J H. Sustainable utilization of China's water resources [J]. Bulletin of Chinese Academy of Sciences, 2012, 27(3): 352–358. Chinese.

[2] GB/T 19923—2005. The reuse of urban recycling water—Water quality standard for industrial uses [S]. Beijing: Standards Press of China, 2005. Chinese.

[3] Xu B X, Li R Y, Wu D B, et al. Utilization status and research progress of brackish water [J]. Journal of Anhui Agricultural Sciences, 2013, 41(36): 13914–13916. Chinese.

[4] Romero-Trigueros C, Parra M, Bayona J M, et al. Effect of deficit irrigation and reclaimed water on yield and quality of grapefruits at harvest and postharvest [J]. LWT-Food Science and Technology, 2017, 85: 405–411.

[5] Wu W Y, Liu H L, Hao Z Y, et al. Review and perspectives of research status on reclaimed wastewater irrigation technologies [J]. Transactions of the CSAE, 2008, 24(5): 302–306. Chinese.

[6] Ministry of Water Resources of the PRC. Chinese water resources bulletin 2015 [M]. Beijing: China Water Power Press, 2016. Chinese.

[7] Dai Z Y, Gao B Z. Research advances in reclaimed water irrigation [J]. Waterresources Protection, 2014, 30(1): 8–13. Chinese.

[8] Huang C G, Wang X. China's farmland sewage irrigation development and its impact on crop research [J]. Journal of Anhui Agricultural Science, 2009, 37(22): 10692–10693. Chinese.

[9] Pan X Y, Wu W Y, Yang S L, et al. Study of reclaimed water irrigation district in Beijing [J]. Journal of Irrigation and Drainage, 2012, 31(4): 115–119. Chinese.

[10] GB 20922—2007. The reuse of urban recycling water-quality of farmland irrigation water [S]. Beijing: Standards Press of China, 2007. Chinese.

[11] Wang Q J, Shan Y Y. Review of research development on water and soil regulation with brackish water irrigation [J]. Transactions of the Chinese Society of Agricultural Machinery, 2015, 46(12): 117–126. Chinese.

[12] Shao Y C, Zhang Y L, Li Y, et al. Technique of brackish water for farmland irrigation [J]. Tianjin Agricultural Science, 2003, 9(4): 25–27. Chinese.

[13] Zhou X N, Liu S Y, Wang Z, et al. The chemical characteristics and available analysis of shallow groundwater in the typical area of plain of North China—Take Hengshui as an example [J]. Water Sciences and Engineering Technology, 2008 (2): 56–59. Chinese.

[14] Bao Z, Liu H L, Wu W Y, et al. The impact of irrigation with reclaimed water on plant [J]. Beijing Water, 2013 (3): 28–31. Chinese.

[15] Wang Q M, Huo Z L, Zhang L D, et al. Impact of saline water irrigation on water use efficiency and soil salt accumulation for spring maize in arid regions of China [J]. Agricultural Water Management, 2016, 163: 125–138.

[16] Chen L, Tian J C, Yan X F. Impact of different irrigation methods with brackish water to cucumber drip irrigation under film in greenhouse [J]. Ningxia Engineering Technology, 2016, 15(2):97–101. Chinese.

[17] Leogrande R, Vitti C, Lopedota O, et al. Effects of irrigation volume and saline water on maize yield and soil in Southern

Italy [J]. Irrigation and Drainage, 2016, 65: 243–253.
[18] Wan S Q, Kang Y H, Wang D. Effect of saline water on tomato growth and yield by drip irrigation in semi-humid regions of North China [J]. Transactions of the CSAE, 2008, 24(8): 30–35. Chinese.
[19] Hao Y Y, Zheng J H, Huang Q Z. Effects of saline water irrigation on soil water salinity and spring maize yield [J]. Journal of Irrigation and Drainage, 2016, 35(10): 36–41. Chinese.
[20] Liu X W, Feike T, Chen S Y, et al. Effects of saline irrigation on soil salt accumulation and grain yield in the winter wheat-summer maize double cropping system in the low plain of North China [J]. Journal of Integrative Agriculture, 2016, 15(12): 2886–2898.
[21] DB13/T 1280—2010. Technical manual for growing winter wheat with slightly saline water irrigation [S]. Hebei Provincial Administration of Quality and Technology Supervision, 2010. Chinese.
[22] Wallender W W, Tanji K K. Agricultural salinity assessment and management [R]. USA: American Society of Civil Engineers, 2011.