Analysis of Tapping Water-Resource Potential for High-Quality Development in Xinjiang

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Abstract

Water scarcity is a key natural factor constraining the high-quality economic and social development of Xinjiang and the construction of its ecological security assurance system. Over the past half century, water conservancy development in Xinjiang has advanced rapidly, effectively supporting healthy and steady economic and social development, yet it still faces many problems and challenges. For example, agricultural water use efficiency needs to be further improved, with considerable potential for water saving. Across Xinjiang, only about 53.34% of the irrigated area has adopted high-efficiency water-saving irrigation, and the figure in southern Xinjiang is only 41.73%; water storage projects remain insufficient, and the engineering control capacity of reservoir projects over water resources is only 20.6%; the potential for water augmentation is unclear, and the utilization of unconventional water resources and the expansion of new sources of water resources remain inadequate; the conversion rate of atmospheric cloud water into precipitation is only 11.3%; and the development and utilization of floodwater and brackish/saline groundwater lag behind. In response, the following measures are proposed: strengthening basic research on the efficient utilization of water resources to substantially improve water use efficiency; vigorously developing agriculture with high water use efficiency to "store water through technology"; promoting autumn and winter irrigation of farmland to "store water in the land"; incorporating wind and solar energy into the agricultural industrial chain to "supplement water with energy"; accelerating the construction of major water conservancy projects and water networks to enhance the capacity to ensure water resource security in response to climate change; strengthening the research and development of technologies for exploiting unconventional water resources to comprehensively expand the space for water resources; and strengthening the research and development of integrated surface water and groundwater utilization models to achieve win-win outcomes for economic development and ecological security.

Full Text

Analysis of Tapping Water-Resource Potential for High-Quality Development in Xinjiang

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Abstract: Water-resource scarcity is a key natural factor constraining the high-quality economic and social development of Xinjiang and the construction of its ecological security guarantee system. Over the past half century and more, water-conservancy construction in Xinjiang has developed rapidly and has effectively supported the healthy and steady development of the economy and society, yet many problems and challenges remain. For example, agricultural water-use efficiency still needs to be further improved, and the potential for water saving is considerable. Across Xinjiang, only about 53.34% of the irrigated area has implemented high-efficiency water-saving irrigation, and in southern Xinjiang the proportion is only 41.73%; construction of water-storage projects is insufficient, and the engineering regulation and control capacity of reservoir projects over water resources is only 20.6%; the potential for increasing water supply is unclear, the utilization of unconventional water and the expansion of space for opening up new water-resource sources are inadequate, and the conversion rate of atmospheric cloud water into precipitation is only 11.3%; the development and utilization of floodwater and slightly saline/brackish groundwater lag behind. In response, this paper proposes: strengthening basic research on efficient utilization of water resources and substantially improving water-resource use efficiency; vigorously developing agriculture with high water efficiency, "storing water in technology"; promoting autumn–winter irrigation of farmland, "storing water in the land"; incorporating wind and solar energy into the agricultural industrial chain, "using energy to supplement water"; accelerating the construction of major water-conservancy projects and water networks to enhance water-resource security capacity in response to climate change; strengthening research and development of technologies for unconventional water-resource development and comprehensively expanding the water-resource space; and strengthening research and development of conjunctive surface-water and groundwater utilization models to achieve a win–win outcome for economic development and ecological security.

Keywords: water-resource potential; slightly saline/brackish groundwater; resource-oriented utilization of floodwater; atmospheric cloud-water resources; Xinjiang

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Xinjiang is located in the arid region of northwest China. It is the core area for the construction of the Silk Road Economic Belt and, even more, a strategic support area for safeguarding national unity in the new era. Since the 18th National Congress of the Communist Party of China, ecological-civilization construction has been integrated into all aspects and the entire process of economic and social development, and the overall ecological situation in Xinjiang has improved: awareness of the ecological environment has increased; the level of water-resource conservation, utilization, and management has improved; the area of surface water bodies has expanded; water-environment quality has improved; water-environment capacity has increased markedly; and the total service value of ecosystems has risen. The areas of natural oases and artificial oases have both increased, the productivity of oasis land has risen substantially, and the oasis ecological environment on which humans depend for survival has improved. Across Xinjiang, sandy land has decreased by 242.8 km^2, realizing a transformation from "sand advancing and people retreating" to "green advancing and sand retreating." The areas of desertified land and sandy land have both shrunk, while vegetation coverage and carbon-sequestration capacity in deserts and sandy lands have continued to increase simultaneously [1], ending the history of being "the only provincial-level region in the country with expanding sandy land." However, as one of China' s major desert regions, Xinjiang has little precipitation and a harsh natural environment. High-quality economic and social development and the construction of an ecological security barrier still face a severe problem of water-resource scarcity.

1 Opportunities and Challenges

1.1 Global warming has led to increased inflow from Xinjiang's mountainous areas

Against the background of global warming, inflow from the mountainous areas of Xinjiang' s major rivers has generally increased, providing Xinjiang with an important window of water-resource opportunity for seizing new opportunities and demonstrating new achievements. Over the past 30 a, Xinjiang' s surface-water resources have increased by about 100×10^8 m^3 and have remained in a state of high-level fluctuation. Of this, southern Xinjiang increased by about 73.6×10^8 m^3; since 2000, runoff in the Aksu River, Yarkant River, Hotan River, and Kaidu River—the four source streams of the Tarim River—has increased by 6.42×10^8 m^3, 9.41×10^8 m^3, 7.67×10^8 m^3, and 6.66×10^8 m^3, respectively (Fig. 1). Research results show that through 2045-2065 of this century, inflow from Xinjiang' s mountainous areas will still maintain high-level fluctuations [2]. Among them, in the Tarim River Basin of southern Xinjiang, inflow from the mountainous areas of some rivers with relatively large glacier-meltwater recharge will still show an increasing trend, with an average increase of 6.25%-7.52% [3-4]. However, indicator-based water scarcity caused by a relatively low red line for water-resource utilization has aggravated resource-based water scarcity; the dividend from the additional 100×10^8 m^3 of surface-water resources added in Xinjiang over the past 20 a has not been fully

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Figure panels: (a) Aksu River; (b) Yarkand River; (c) Hotan River; (d) Kaidu River.
Axes: Year; hydrological frequency / %.

Note: The smaller the hydrological-frequency value, the more abundant the runoff; the larger the hydrological-frequency value, the drier the runoff. For the Aksu River, the value is the sum of the runoff of the Kumarik River and the

Toshkan River plus interval water yield; for the Hotan River, it is the sum of the runoff of the Yurungkash River and the Karakash River.

Fig. 1 Annual runoff frequency of the Aksu, Yarkand, Hotan, and Kaidu rivers in southern Xinjiang during 1957-2024

release and effective utilization.

1.2 Winning the Blocking Battle on the Taklimakan Desert Urgently Requires Support and Safeguards from Water Resources

The Taklimakan Desert is the world' s second-largest shifting desert, with a total area of 33.76×10^4 km^2. Shifting dunes account for more than 70% of this area. The region has scarce precipitation, strong winds, and uneven spatiotemporal distribution of water resources; both engineering-based sand control and biological sand control are constrained by the rigid requirement of "determining greening by water," and the natural environment is extremely harsh[1]. Winning the blocking battle along the edge of the Taklimakan Desert is one of the three landmark campaigns of the "Three-North" Project in the new era. It aims to curb desert expansion, safeguard oasis security, and strengthen the northern ecological barrier. Over the past 3 years, through combined measures such as biological sand control, engineering sand control, and photovoltaic-plus-sand-control approaches, comprehensive desert edge-locking was carried out in the 285 km gap zone along the southern margin of the Tarim Basin. On 28 November 2024, the 3,046 km green sand-blocking shelterbelt around the Taklimakan Desert achieved complete "edge-locking closure." This project is an important achievement in the construction of China' s "Three-North" Shelterbelt System and a landmark event in the history of China' s desertification control. At the 2025 General Assembly of the World Federation of Engineering Organizations (WFEO), held in October 2025, it was officially selected as one of the "2025 Global Top Ten Engineering Achievements." However, after the Taklimakan Desert was enclosed, efforts to consolidate the edge, expand the edge, and improve quality and efficiency still face multiple severe challenges. The maintenance and conservation of the constructed biological-engineering measures, as well as the long-term stability of vegetation, are closely related to water-supply capacity. Winning—and winning well—the blocking battle along the edge of the Taklimakan Desert urgently requires support and safeguards from water resources.

1.3 The Demand for Water-Security Guarantees for High-Quality Development in Xinjiang Is Increasing Day by Day

The state has assigned Xinjiang important strategic roles: the core area for the construction of the Silk Road Economic Belt, a strategic pivot in the new de-

[1] Government website of the National Forestry and Grassland Administration: "Taklimakan Desert Edge-Locking Project Selected as a '2025 Global Top Ten Engineering Achievement' " (https://xxfb.forestry.gov.cn/c/www/gjgyly/646478.jhtml).

velopment pattern, a national strategic support base for energy and resources, an important national supply base for high-quality agricultural and pastoral products, and a strategic barrier for safeguarding national geopolitical security. Xinjiang' s high-quality development has entered a new stage. At the same time, higher requirements have been put forward for the systematic, stable, and sustainable guarantee of water security across the entire region. However, Xinjiang is affected by the intertwined problems of resource-based, engineering-based, management-based, and quota-based water shortages, leaving regional high-quality development facing severe water-use difficulties. Meanwhile, with the construction of the core area of the Silk Road Economic Belt and the large-scale development of energy bases and specialty agriculture, water demand continues to grow. Water-security guarantees have evolved from traditional water-supply guarantees to a systemic requirement for coordinated security among resources, ecology, the economy, and society. Therefore, systematically carrying out research on tapping the potential of water resources is both a core urgent need and an inevitable pathway for breaking the water constraints on Xinjiang' s development and strengthening the national water-security barrier in western China. It is also an important measure to seize the window of increased water availability brought about by climate change and, through innovative source expansion, release the carrying capacity of water resources, so as to reduce

the risks of water-resource fluctuations brought about by low-climate transition, and provide a stable and reliable water-security guarantee for Xinjiang' s long-term stability and high-quality development.

2 Problems and Shortcomings

The state attaches great importance to the construction of water-conservancy infrastructure in Xinjiang. In view of the characteristics of Xinjiang's desert oases and irrigated agriculture, through forward-looking thinking, overall planning, and integrated advancement, it has accelerated the construction of Xinjiang' s main water-network framework and major arteries, commenced construction of a large number of water-conservancy projects, and worked to enhance Xinjiang' s water-resource regulation and storage capacity. It has vigorously promoted water-saving technologies, continuously strengthened intelligent water-resource management, and effectively addressed regional, seasonal, and structural water shortages. Nevertheless, there remain many shortcomings that urgently need to be remedied in water saving, water storage, water augmentation, unconventional water-resource utilization, and potential tapping.

2.1 Low efficiency of water-resource utilization and considerable potential for agricultural water saving

The efficiency of agricultural water use needs to be further improved. Agriculture is Xinjiang' s major water user; under current conditions, both the level of water-saving intensive use in agriculture and water-use efficiency need further improvement. Of Xinjiang's 7.85×10^4 km^2 of irrigated area, only about 53.34%

has adopted high-efficiency water-saving irrigation, and in southern Xinjiang the proportion is only 41.73%. The actual utilization rate of high-efficiency water-saving irrigation already constructed across Xinjiang is 83.38%, and in southern Xinjiang it is 67.8%. The average seepage-control rate of Xinjiang' s three-level main–branch–lateral canal system is only 64.35%; the seepage-control rate of lateral canals is only 53.04%, and that of farm canals is even lower. The effective utilization coefficient of irrigation water in southern Xinjiang is only 0.534; agricultural water-use efficiency still needs to be improved, and the potential for agricultural water saving remains considerable. Therefore, the research, development, demonstration, and promotion of efficient water-saving irrigation technology models urgently need to be strengthened, so as to promote overall quality and efficiency improvement in agriculture and rural revitalization[6].

The technical pathways and models for high-standard farmland construction and irrigation-district upgrading need to be optimized. At the present stage, cultivated land in counties and cities across Xinjiang commonly suffers from small plot size and a high degree of fragmentation, especially in southern Xinjiang. Land fragmentation, as well as traditional forestry–agriculture intercropping models and modes of agricultural production, restrict the high-standard upgrading of cultivated land and the promotion of water-saving measures; excessively dense farmland shelterbelts within irrigation districts increase groundwater consumption and water-resource waste[7–8]. Strengthening the research and development of technologies and models for high-standard farmland construction—especially in southern Xinjiang—and accelerating the consolidation of fragmented land and the upgrading of irrigation districts are of great significance for implementing large-area water-saving technology promotion and improving the modernization level of agriculture.

A modern agricultural development pathway for coordinated protection of water–energy–food–ecological security urgently needs to be developed. Agricultural water use in Xinjiang accounts for about 93.5% of Xinjiang' s total water use; improving agricultural water-use efficiency and doing a good job in agricultural water saving are the basic guarantees for Xinjiang to implement the Party Central Committee' s policy of prioritizing water conservation. At the present stage, agricultural water saving in Xinjiang is still mainly concentrated on canal-system seepage control, field-level high-efficiency water-saving irrigation, and subsurface drip irrigation, among other engineering field-level water-saving measures[9]. In response to Xinjiang's resource-based water shortage, soil salinization, and the needs of high-quality agricultural development, research and development remain insufficient for technical pathways and key technical models that integrate modern agriculture and agricultural water-saving technologies, high-water-efficiency agricultural development, and the advantages of regional wind and solar energy resources for coordinated water–energy–food development, so as to enable water supplementation, coordinated protection of water–energy–food–ecological security, research on modern high-water-efficiency agricultural technologies, and the tapping of water-saving potential in different regions; this should be further strengthened[10–11].

2.2 Insufficient construction of water-storage projects and declining capacity for water-resource regulation and storage

2.2.1 Lagging construction of water-conservancy projects and insufficient water-regulation and storage capacity Xinjiang currently has 669 reservoirs of various types, with a total storage capacity of 236.34×10^8 m^3; its water-resource regulation and storage capacity is only 20.6%, far below the national average. Southern Xinjiang has 189 reservoirs of various types, including 145 plain reservoirs, accounting for 76.7%; the capacity of water-conservancy projects to regulate and control water resources is seriously low[12]. In southern Xinjiang, especially on the northern slope of the Kunlun Mountains, there is a serious shortage of control backbone projects for numerous small rivers with runoff of around 1.0×10^8 m^3. Construction of storage projects in various basins lags seriously, and water-resource regulation and storage capacity is only 10%–15%. As a result, surface water resources in many medium and small rivers with short flow paths and strong seasonality are difficult to use effectively, and engineering-type water shortage is prominent[10].

2.2.2 The level of reservoir potential tapping and joint use and operation of lakes, reservoirs, and wetlands needs to be improved The development, utilization, and safety guarantee of Xinjiang' s water resources are still constrained in many respects, including regulation and storage projects, the water-network system, and hydrological connectivity. First, Xinjiang still lacks controlling regulation and storage reservoirs in mountainous areas. The storage capacity of most plain reservoirs has declined because of siltation, risks have increased, and it has become difficult for them to fully exert their due regulation and storage capacity; desilting of reservoirs and tapping of storage-capacity potential urgently need to be carried out[13–14]. Second, Xinjiang' s modern water-network system is still in the stage of accelerated construction and improvement. Inter-basin and cross-regional water-transfer projects oriented toward optimizing regional water–soil resources and spatially balanced allocation of water resources still need to be advanced more quickly. In response to agricultural droughts and inadequate water-risk capacity caused by global change, the construction of Xinjiang' s water-security and water-network system urgently needs to be accelerated[15]. Third, with Xinjiang dominated by inland river basins, there is generally insufficient hydrological connectivity; climate change has intensified hydrological fluctuations and increased the uncertainty of water-security assurance[16]. It is urgent to accelerate research on river–lake–reservoir water-system connectivity pathways and technical models and schemes for the joint use of lakes–reservoirs–wetlands; to develop technologies and schemes for the joint use and coordinated optimal management of river-lake–reservoir, reservoir–reservoir, and reservoir–lake–wetland systems; to make full use of resource and environmental conditions; and to build a water-security optimization pattern combining "diversion, storage, irrigation, and drainage," realizing mutual support between abundance and scarcity, mutual supplementation between floods and droughts, and spatial coordination, so as to address the challenges brought by climate change and the increase in extreme hydrometeorological events[17].

2.2.3 Breakthroughs are urgently needed in storage, diversion, and conveyance technologies for sediment-laden small and medium-sized rivers

On the southern slope of the Tianshan Mountains and the northern slope of the Kunlun Mountains, there are numerous small and medium-sized rivers with short courses and steep gradients. Their runoff is unevenly distributed within the year and strongly seasonal, and their water has a high sediment content. In the processes of storage, diversion, conveyance, and utilization, sediment-laden rivers face technical constraints such as sediment deposition, sand interception at canal heads, sediment settling and flushing, and filtration treatment. Relevant engineering models and operation technologies still need improvement, resulting in the surface-water resources of these sediment-laden rivers during flood periods not yet being effectively developed and utilized[18]. Therefore, it is urgent to accelerate research and development on diversion hubs and water-intake and utilization technologies for sediment-laden rivers, and to improve the efficiency of water-resource use and the allocation capacity of small and medium-sized rivers in southern Xinjiang.

2.3 Unclear potential for water augmentation, and insufficient expansion of unconventional water use and water-resource development space

2.3.1 Atmospheric cloud-water resources have enormous development potential, and related technology R&D urgently needs strengthening

Xinjiang is located in the region influenced by the mid-latitude westerlies, and regional water-vapor input is mainly controlled by westerly water-vapor transport. Existing studies show that the annual water-vapor input over Xinjiang can reach 2.05×10^{12} t, indicating abundant atmospheric cloud-water resources[19]. However, key technical models for developing atmospheric cloud-water resources have not yet been fully established, and breakthroughs are urgently needed in key technologies for cloud-water resource development and utilization in order to greatly enhance the capacity to develop and utilize atmospheric cloud-water resources. At present, the conversion rate of atmospheric water vapor over Xinjiang into precipitation is only 11.3%, lower than the averages for Northwest China (15.4%) and the whole country (34.0%); thus, atmospheric cloud-water resources have tremendous potential for water augmentation. It is urgently necessary to intensify the development of atmospheric cloud-water resources, store water and conserve its sources, and thereby make up for Xinjiang' s shortcoming of resource-based water scarcity[20].

2.3.2 Development and utilization of brackish/saline water lag behind, and key technologies urgently need breakthroughs

The plain desert areas and desert interiors of Xinjiang contain considerable reserves of groundwater saline resources. Among them, in the southern Xinjiang plain area, the annual recharge of saline water with mineralization greater than $2\ \mathrm{g}\cdot\mathrm{L}^{-1}$ is approximately $44.4 \times 10^8\ \mathrm{m}^3$. Scientific utilization of brackish/saline water resources is of great significance for expanding Xinjiang' s water-resource space. In recent years, relevant policies in Xinjiang have proposed the comprehensive use of shallow groundwater with mineralization greater than $2\ \mathrm{g}\cdot\mathrm{L}^{-1}$ within irrigation districts for sand prevention and control. Hotan, Aksu, and other areas have also explored the use of saline water for drip irrigation of sand-fixing plants such as *Haloxylon*, providing supplementary ecological water sources for the campaign to block the expansion of the Taklimakan Desert at its margins[21]. However, existing technologies for brackish-water treatment and brackish-water use, as well as successful demonstration cases, remain clearly insufficient; investigation and evaluation of brackish-water potential and its development and utilization are relatively lagging. Research and technological breakthroughs related to the development and utilization of brackish/saline water should be accelerated, so as to improve the level of brackish/saline water development and utilization in the plain desert areas of southern Xinjiang and provide important water-resource support for the construction of biological sand-control projects to seal the margins of the Taklimakan Desert.

2.3.3 Development of difficult-to-use water resources in the Qiangtang Plateau region and utilization of karst groundwater should be strengthened

Over the past 30 a (1990–2023), under the influence of climate change, water resources in the inland-river region of the Qiangtang Plateau within Xinjiang have shown a significant increasing trend, manifested as significant increases in both the number of mountain lakes and the area of lake water bodies. For example, in the Kumukuli Basin of the East Kunlun Mountains, the areas of the three major lakes—Ayakekumu Lake, Aqikkule Lake, and Jingyu Lake—expanded respectively from 669.16 km^2 to 1141.67 km^2, from 386.65 km^2 to 617.89 km^2, and from 263.67 km^2 to 399.30 km^2[18]. Ayakekumu Lake has already become the lake with the largest water-surface area in Xinjiang. Preliminary statistics indicate that the water storage of the three major lakes exceeds $200 \times 10^8\ \mathrm{m}^3$. Moreover, according to the results of Xinjiang' s third scientific expedition, with increasing mountain precipitation and the melting of ice and snow, the lakes in this region will continue to expand. In addition, large areas of carbonate-rock strata are developed in the Tianshan Mountains, and karst groundwater resources are considerable. Scientific exploration of pathways for diverting water down from the Qiangtang Plateau region and for developing and utilizing mountain karst groundwater resources will provide a scientific basis for further expanding the space for developing and augmenting Xinjiang' s water resources.

3 Countermeasures and recommendations

Based on an analysis of Xinjiang' s locational characteristics and resource endowments, in the future layout of national development strategies, Xinjiang—while shouldering responsibilities for national defense security, political security, and ecological security—can also make important Xinjiang contributions to national energy security, food security, and the construction of China' s ecological security barrier. However, water-resource shortages seriously constrain the sustainable, high-quality economic and social development of Xinjiang. Therefore, it is recommended that, in light of Xinjiang' s core positioning in the construction of the Silk Road Economic Belt, and in combination with the increasing trend of Xinjiang' s surface-water resources over the past nearly 20 a and future development trends, the state scientifically assess Xinjiang' s important position in safeguarding national defense security, energy security, food security, and ecological security; make scientific projections; substantially raise the upper limit of water-resource use; determine cities, land, population, and production according to water availability; actively tap potential and increase water supply to expand the space for water-resource utilization; vigorously promote water-saving technologies to improve water-resource use efficiency; and actively advance water-conservancy construction to enhance water-resource management, control, and allocation capacity. Through "four-dimensional" efforts in water saving, water storage, water transfer, and water augmentation, and through multidimensional breakthroughs in the bottlenecks of resource-based water scarcity, engineering-based water scarcity, and seasonal water scarcity, water-use policy support and guidance can be provided for Xinjiang' s ecological security and sustainable high-quality development, enabling Xinjiang to contribute to ensuring national defense security, energy security, food security, and ecological security.

3.1 Strengthen basic research on efficient water-resource utilization and substantially improve water-resource use efficiency

(1) With the goal of providing water-resource security to support national development strategies and Xinjiang' s "five strategic positionings," comprehensively strengthen the construction of Xinjiang's water-resource monitoring system and big-data system, and strengthen basic theoretical research on water-cycle mechanisms and water-security assurance under the background of global change;

(2) Scientifically evaluate the changing state and future trends of Xinjiang' s water resources, and, in response to intensified hydrological fluctuations and uncertainty in water resources under the background of climate change,

enhancement of this objective reality, it is recommended that, on the basis of water-resource control indicators, scientific water-resource allocation plans be formulated; (3) scientifically assess and redetermine the ecological discharge indicators for the upstream source rivers of the Tarim River Basin into the mainstream of the Tarim River. It is recommended that the ecological water-release indicator from the Daxihaizi Reservoir in the lower Tarim River be reduced from 3.5×10^8 m^3 per year to 1.5×10^8 m^3, with coordinated replenishment by the Tarim River and the Qarqan River. The water area of Taitema Lake, the terminal lake of the river system, should not be excessively large; it is advisable to maintain it at about $20 \sim 30$ km^2, so as to cultivate and enhance the ecological functions of the Taitema Lake wetland; (4) raise the upper limit of water-resource utilization on the northern slope of the Kunlun Mountains-southern margin of the Tarim Basin to $65\% \sim 70\%$. On the basis of the carrying capacity of water resources, further optimize the pattern of water and land resource development, build an economic belt on the northern slope of the Kunlun Mountains, and make Xinjiang' s contribution to winning the Hexi Corridor–Taklimakan Desert fringe blocking campaign and to the national effort to increase grain production capacity by 100 billion jin .

3.2 Accelerate the construction of a water-saving society and fully implement the central strategy for high-standard farmland development

(1) Continuously strengthen agricultural water conservation, vigorously develop high-water-efficiency agriculture, and "store water through technology." Relying on biotechnology, agronomic technology, and intelligent equipment, promote the construction of a new agricultural water-use system featuring precise water use and maximized water benefits; accelerate the renovation of irrigation districts and the construction of high-standard farmland; speed up the consolidation of fragmented land; and, in combination with connected oasis belts along the desert edge, the improvement and utilization of saline-alkali land, and other measures, gradually complete the integration and governance of cultivated land in southern Xinjiang, thereby creating conditions for the large-scale promotion of water-saving technologies and the development of modern agriculture.

(2) Develop pipeline water conveyance in accordance with local conditions, accelerate anti-seepage renovation of canal systems—especially the construction of the last kilometer of lateral and farm canals—strengthen supporting field-level water-saving facilities, promote the practical implementation and widespread use of efficient water-saving measures, and improve the efficiency of water-resource utilization.

(3) Under the current conditions of few reservoirs and weak engineering capacity to control and regulate water resources, "store water in the ground." Strengthen autumn and winter irrigation of farmland—autumn irrigation for orchards and winter irrigation for farmland—to recharge groundwater and increase soil moisture, thereby laying a foundation for "dry sowing and moist emergence" during the spring dry-water period of the following year.

(4) Make full use of Xinjiang' s advantages in wind and solar energy resources; develop large-scale facility agriculture and modern intelligent greenhouses; incorporate wind and solar energy into the agricultural industrial chain so that energy can supplement water; increase water-use output efficiency and land productivity; build an alternative economic development model between water resources and energy; and realize coordinated development of water, energy, and grain.

3.3 Accelerate the construction of major water-conservancy projects and enhance the capacity to safeguard water-resource security in response to climate change

(1) Accelerate the construction of major water-diversion projects, backbone controlling water-conservancy projects in mountainous areas, and Xinjiang' s water-network projects. Strengthen connectivity among river–lake–reservoir–wetland water systems between and within basins, joint utilization of water resources, and the construction of irrigation-district water-network projects, so as to complement wet and dry conditions, provide mutual support, and improve the capacity for spatially balanced allocation of water resources in response to the challenges brought by climate change. (2) Accelerate the research and development of engineering technologies and scheme design for water storage, intake, and conveyance in sediment-laden rivers; accelerate feasibility studies and water-conservancy construction for controlling water-conservancy projects on medium and small sediment-laden mountain rivers of $1 \times 10^8 \sim 2 \times 10^8$ m^3 on the northern slope of the Kunlun Mountains in southern Xinjiang in particular; and accelerate the construction of desilting basins and small water-source projects in sandy areas. Develop technologies for water intake, conveyance, and use in sediment-laden rivers—such as subsurface-flow interception by infiltration pipes and modern karez water-conveyance technology combined with pipeline gravity diversion—to improve the efficiency of water-resource utilization. (3) Accelerate feasibility studies on diverting water from the Qiangtang Plateau down from the mountains and research on development and utilization pathways for difficult-to-use water resources in plateau areas, thereby further expanding the source-opening space for Xinjiang' s water resources.

3.4 Strengthen research and development of unconventional water-resource development technologies and comprehensively expand water-resource space

(1) Accelerate the research, development, and application of technologies for exploiting airborne cloud-water resources, and actively carry out artificial precipitation enhancement in mountainous areas to "store water and nourish sources." It is recommended that cloud-water resource development and utilization be carried out first in the severely water-deficient

eastern Tianshan Mountains and the Turpan–Hami Basin. (2) Increase the resource-oriented utilization of floodwater during the flood season. By means of reservoir operation and regulation, river-network storage and regulation, and other approaches, and through ecological water-conservancy projects such as "dredging, guiding, and diverting," realize the resource-based ecological utilization of floodwater, including floodwater diversion for irrigation, ecological restoration, agricultural irrigation, groundwater recharge, sediment flushing and silt reduction, and reservoir capacity expansion, thereby expanding water-resource space from the perspective of "source opening." (3) Increase the development and utilization of brackish/saline water in the Tarim Basin of southern Xinjiang. Combine the extraction and utilization of underground brackish/saline water with the Taklimakan Desert fringe blocking campaign, saline-alkali land 治理, and saline-water aquaculture; and, in conjunction with the consumption and utilization of regional wind and photovoltaic new energy, accelerate key technological research and development for the resource-based application of brackish groundwater, including high-efficiency, low-cost desalination, hydrogen production, and ecological water replenishment. Through the ecological utilization of brackish/saline groundwater resources in desert areas, expand regional water-resource space to compensate for the shortage of freshwater resources [10–11]. (4) Strengthen the comprehensive recovery and utilization of urban and industrial reclaimed water and local agricultural drainage, realize the substitution of reclaimed water and agricultural drainage for ecological water use, and replace freshwater for regional national economic development. Improve and perfect relevant management mechanisms and systems, clarify water-rights relationships, formulate and use guidance and incentive mechanisms, and enhance water-security 保障 levels in multiple dimensions.

3.5 Strengthen refined management of groundwater resources and accelerate research and development of a joint surface-water-groundwater utilization model

(1) Strengthen refined management of groundwater resources and monitoring of groundwater-level changes, and carry out systematic survey and evaluation of the recoverable amount of groundwater across Xinjiang. According to the occurrence conditions of groundwater resources in different regions and different geographic units, implement regionalized management of groundwater development and utilization indicators, and scientifically determine development thresholds. (2) Implement the strictest water-resource management in groundwater overexploitation areas, apply "dual control of wells and electricity," and make full use of floodwater during the flood season⋯

Chinese Government Website: China fully implements a new round of action to increase grain production capacity by 100 billion jin, 2024 (https://www.gov.cn/lianbo/bumen/202404/content_6944034.htm).

water available during the winter agricultural slack season, and winter power-generation tailwater from mountain hydropower stations; scientifically implement winter irrigation and summer flood-diversion irrigation, replenish groundwater, and maintain a balance between extraction and recharge. (3) Accelerate the implementation of interbasin water transfers. For areas with severe water shortages, such as the northern slope of the Tianshan Mountains, eastern Tianshan, and the Hami region, interregional water transfers may be used to replace groundwater development and utilization. At the same time, accelerate the development of atmospheric cloud-water resources in this region to supplement the shortage of water resources. (4) Accelerate research on the transformation and migration of surface water and groundwater, as well as groundwater-resource endowment; actively explore integrated surface-water and groundwater utilization and allocation schemes suited to Xinjiang' s mountain–basin geomorphic structure; optimize the integrated utilization model for surface water and groundwater; and, on the basis of maintaining ecological improvement, make full use of the precious water resources in arid areas.

References

[1] Noor S A, Jiang X, Wang X, et al. Human-induced biospheric carbon sink: Impact from the Taklamakan Afforestation Project[J]. Proceedings of the National Academy of Sciences, 2026, 123(4): e2523388123, doi: 10.1073/pnas.2523388123.

[2] Yang Z L, Bai P. Response of runoff and its components to climate change in the Manas River of the Tian Shan Mountains[J]. Advances in Climate Change Research, 2024, 15(1): 62–74.

[3] Fang G H, Li Z, Chen Y N, et al. Projecting the impact of climate change on runoff in the Tarim River simulated by the soil and water assessment tool glacier model[J]. Remote Sensing, 2023, 15(16): 3922, doi: 10.3390/rs15163922.

[4] Wortmann M, Duethmann D, Menz C, et al. Projected climate change and its impacts on glaciers and water resources in the headwaters of the Tarim River, NW China/Kyrgyzstan[J]. Climatic Change, 2022, 171: 30, doi: 10.1007/s10584-022-03343-w.

[5] Zhu Z D. Aeolian landforms in the Taklimakan Desert[C]//El-Baz F. *Deserts and Arid Lands*. Dordrecht: Springer, 1984: 133–143.

[6] Yin Lihe, Zhang Jun, Jiang Jun, et al. Issues and countermeasures on water resources in southern Xinjiang[J]. Geology in China, 2023, 50(1): 1–12.

[7] Jia Zhiqing, Hao Guangyou, Jia Ling, et al. Prospects for research on technologies for enhancing and securing water and soil resource ecological safety in the arid desert oasis regions of northwest China[J/OL].

Science of Soil and Water Conservation. [2025-10-11]. https://zgstbkx.xml-journal.net/article/doi/10.16843/j.sswc.2025174.

[8] Fu S, Sun L, Luo Y. Combining sap flow measurements and modeling to assess water needs in an oasis farmland shelterbelt of *Populus simonii* Carr in northwest China[J]. Agricultural Water Management, 2016, 177: 172–180.

[9] Li Yunxia, Fan Cheng, Guan Xinyuan, et al. Status and countermeasures of agricultural water-saving development in irrigation areas of Xinjiang[J]. Journal of Huazhong Agricultural University, 2024, 43(2): 93–98.

[10] Chen Yaning, Zhu Chenggang, Li Zhi, et al. High-quality development in the northern slope of the Kunlun Mountains: Issues, opportunities and challenges[J]. Arid Land Geography, 2024, 47(5): 733–740.

[11] Chen Yaning, Li Zhongqin, Xu Jianhua, et al. Changes and protection suggestions in water resources and ecological environment in arid region of northwest China[J]. Bulletin of Chinese Academy of Sciences, 2023, 38(3): 385–393.

[12] Liu Jianjun. Problems and countermeasures of water resources guarantee in south Xinjiang[J]. Water Resources Development and Management, 2022, 8(8): 8–11.

[13] Li Jiang, Liu Jianxin, Liu Shengyun, et al. Main problems and countermeasures of reservoir dam construction in Xinjiang in the new period[J]. Arid Land Geography, 2020, 43(6): 1409–1416.

[14] Deng Mingjiang. Research and thinking on water resources problems in Xinjiang[J]. Quaternary Sciences, 2010, 30(1): 107–114.

[15] Kang Haoyan. Xinjiang will accelerate the construction of a modern water network this year[N]. Xinjiang Daily, 2026-02-08.

[16] Chen Y N, Li W H, Deng H J, et al. Changes in Central Asia' s water tower: Past, present and future[J]. Scientific Reports, 2016, 6: 35458, doi: 10.1038/srep35458.

[17] Chen Yaning, Li Weihong, Chen Yapeng, et al. Study on water system connectivity and ecological protection countermeasures of Tarim River Basin in Xinjiang[J]. Bulletin of Chinese Academy of Sciences, 2019, 34(10): 1156–1164.

[18] Zhu Chenggang, Chen Yaning, Zhang Mingjun, et al. Preliminary report on scientific investigation of water resources on the northern slope of Kunlun Mountains[J]. Arid Land Geography, 2024, 47(7): 1097–1105.

[19] Yao Junqiang. Study on the variation characteristics of atmospheric water resources and surface water resources in Xinjiang[J]. *Arid Zone Research*, 2024, 41(2): 181–190. [Yao Junqiang. Change in atmospheric and surface water resource in Xinjiang[J]. Arid Zone Research, 2024, 41(2): 181–190.]

[20] Zhang Qiang, Wang Yuan, Zhang Ping. On the characteristics of atmospheric cloud-water resources and the cloud-to-precipitation conversion mecha-

nism in Northwest China[J]. *Advances in Earth Science*, 2025, 40(5): 473–486. [Zhang Qiang, Wang Yuan, Zhang Ping. Cloud water resources and precipitation conversion in northwest China[J]. Advances in Earth Science, 2025, 40(5): 473–486.]

[21] Tuerxunjiang Tuohutiaji, Abudukere Wujiaaibai. A brief discussion on the utilization of brackish water in Bachu County, Kashgar Prefecture[J]. *Hydropower and Water Resources*, 2024, 8(3): 22–24. [Tuohutiajı Tuerxunjiang, Wujiaaibai Abudukere. A brief discussion on the utilization of brackish water in Bachu County, Kashgar Prefecture[J]. Hydropower and Water Resources, 2024, 8(3): 22–24.]

Unlocking the potential of water resources for high-quality development in Xinjiang

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Abstract: Water scarcity is a major natural constraint on high-quality socioeconomic development and ecological security in Xinjiang. Over the past half century, water conservancy development has advanced rapidly and effectively supported stable and sustainable socioeconomic development in the region. However, several critical challenges remain. For example, agricultural water-use efficiency still requires substantial improvement, indicating considerable water-saving potential. Currently, only ~53.34% of the irrigation area in Xinjiang has adopted high-efficiency water-saving irrigation technologies, while the proportion in southern Xinjiang is only 41.73%. Water storage infrastructure remains insufficient, and reservoir projects control only 20.6% of total water resources. In addition, the potential for water-resource augmentation remains insufficiently explored. The utilization of unconventional water resources and the development of new water resources remain limited. The conversion rate of atmospheric cloud water into precipitation is only 11.3%, and the utilization of floodwater and brackish/saline groundwater is underexplored. To address these challenges, this study proposes several measures. These include strengthening basic research on efficient water-resource utilization and substantially improving water-use efficiency; vigorously developing high-water-efficiency agriculture and implementing "storing water through technology"; promoting autumn and winter irrigation of farmland and "storing water underground"; integrating wind and solar energy into the agricultural industrial chain and implementing "supplementing water with energy"; accelerating the construction of major water conservancy projects and water network systems to enhance water-resource security under climate change; strengthening research and development of technologies for exploiting unconventional water resources to comprehensively expand water-resource availability; and promoting the integrated use of surface water and groundwater to achieve coordinated economic development and ecological security.

Keywords: water resources potential; saline groundwater; floodwater resource utilization; atmospheric cloud water resources; Xinjiang

Note: Figure translations are in progress. See original paper for figures.