Development of Irrigated Agriculture in Uzbekistan and Its Impacts on Ecological Environment and Economic Development: Postprint

Authors: Li Qi

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Abstract

As a major agricultural nation in the arid region of Central Asia, irrigation serves as the primary controlling factor for Uzbekistan' s agricultural production due to its distinctive climatic conditions. Therefore, investigating the developmental trajectory of its irrigation agriculture holds significant importance for safeguarding agricultural production and natural environmental security. Through reviewing pertinent literature in the field of Uzbekistan' s irrigation agriculture development and integrating data provided by official websites such as the Food and Agriculture Organization of the United Nations and the United Nations Data Retrieval System, this study summarizes the variation patterns of irrigated farmland area, population, major crop yields, and agricultural output value, elucidates the developmental history of irrigation agriculture in Uzbekistan, and analyzes and discusses a series of environmental issues induced by agricultural irrigation along with their socio-economic impacts. The findings indicate: (1) Owing to an arid climate with low precipitation, irrigation water in Uzbekistan is primarily sourced from the Amu Darya and Syr Darya rivers. The continuous decline in downstream river discharge and water storage volume of the Aral Sea has exposed substantial loose sediments within riverbeds, resulting in frequent dust storm events. (2) Overall, agricultural irrigation technology in Uzbekistan remains relatively underdeveloped. Excessive water diversion causes partial surface runoff to converge in low-lying areas of irrigation zones, elevating groundwater tables and ultimately inducing severe regional soil salinization. Consequently, the comprehensive promotion of advanced irrigation and drainage technologies constitutes the principal direction for the healthy development of the nation' s future irrigation agriculture and ecological environment. (3) Agricultural production represents a crucial source of economic revenue for Uzbekistan and exerts a significant positive influence on its Gross Domestic Product. This study can provide valuable insights for agricultural development and water resource management in arid regions.

Full Text

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LI Qi[1,2], **LI Fadong**[1,2,3], **WANG Guoqin**[1,4], **QIAO Yunfeng**[1,3], **PENG Yu**[1,3], **LIU Hongguang**[2], **HE Xinlin**[2], **YANG Guang**[2], **Rashid KULMATOV**[5], **Sayidjakhon KHASANOV**[6]

[1]Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[2]College of Water Conservancy and Architectural Engineering, Shihezi University, Shihezi 832000, Xinjiang, China
[3]University of Chinese Academy of Sciences, Beijing 100049, China
[4]United Nations Environment Programme International Ecosystem Management Partnership (UNEP IEMP), Beijing 100101, China
[5]National University of Uzbekistan, Tashkent 100170, Uzbekistan
[6]Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Tashkent 100000, Uzbekistan

Abstract

Uzbekistan represents a major agricultural nation in the arid regions of Central Asia, where irrigation serves as the primary controlling factor for agricultural production due to its unique climatic conditions. Consequently, studying the development history of its irrigated agriculture holds significant importance for safeguarding both agricultural production and natural environmental security. By reviewing relevant literature on irrigated agricultural development in Uzbekistan and integrating data from official sources such as the Food and Agriculture Organization of the United Nations and the United Nations Data Retrieval System, this study summarizes the changing patterns of irrigated farmland area, population, major crop yields, and agricultural output value. The paper elaborates on the developmental trajectory of irrigated agriculture in Uzbekistan and analyzes a series of environmental issues arising from agricultural irrigation and their socioeconomic impacts. The results indicate that: (1) Due to the arid climate with minimal rainfall, Uzbekistan' s irrigation water primarily originates from the Amu Darya and Syr Darya rivers, leading to continuous decline in downstream river runoff and water storage in the Aral Sea, exposing large quantities of loose sediments on the exposed riverbed and causing frequent dust storms. (2) Uzbekistan' s agricultural irrigation technology remains relatively backward, and excessive water diversion has caused some surface runoff to accumulate in low-lying areas of irrigation districts, raising groundwater levels and ultimately triggering severe regional soil salinization. Therefore, comprehensive promotion of advanced irrigation and drainage technology represents the main direction for the healthy development of the country' s future irrigated agriculture and ecological environment. (3) Agricultural production constitutes an important economic source for Uzbekistan, exerting a significant positive influence on gross domestic product. This research can provide scientific support for agricultural development and water resource management in arid regions.

Keywords: irrigation; arid land; agriculture; cotton; wheat; Uzbekistan; Central Asia

1 Introduction

In recent years, agricultural production in arid regions has gradually become one of the primary factors causing environmental degradation, with the contradiction between growing food demand and fragile environmental conditions becoming increasingly prominent. Global food production is projected to increase by 100%~110% by 2050 compared to 2005 levels. Improving agricultural production efficiency in low-productivity regions can achieve global food production increase goals while maximizing natural environmental protection. Crop yield variation depends largely on local fertilizer application rates and irrigation management. Dryland regions, as important components of terrestrial environments, cover over 40% of global land area and support 38% of the world' s population. Central Asia, characterized by typical arid climate conditions, has experienced significant environmental changes due to intensive human activities and frequent extreme climate events.

As a typical agricultural country in Central Asia, Uzbekistan possesses a long history of agricultural irrigation, with its agricultural production contributing nearly 30% of gross domestic product (GDP), of which irrigated land provides over 95% of crop yields. The Syr Darya and Amu Darya rivers serve as Uzbekistan' s most important irrigation water sources, supplying water to 42% and 58% of irrigated farmland respectively. However, these rivers' runoff is significantly affected by precipitation variations and snow water storage capacity, with both rivers' flow decreasing by approximately 30% within the past 40 years. Throughout its history, Uzbekistan' s major crops have gradually transitioned from cotton to a balanced development of cotton and wheat. Currently, cotton water consumption accounts for about 60%~70% of total agricultural water use, with almost complete dependence on irrigation. In contrast, winter wheat can obtain partial water supply from rainfall, with wheat consuming only 40% of the water used by cotton for the same area. This adjustment in planting structure has alleviated agricultural water tension to some extent.

During the 1970s, the Soviet government allocated funds to construct the Great Fergana Canal to alleviate Uzbekistan' s water difficulties. However, limited by scarce water resources, its agricultural development entered a bottleneck period. After the dissolution of the Soviet Union, Uzbekistan' s agricultural irrigation continued to rely on reservoirs and long-distance water conveyance channels. Inefficient earthen channel delivery and extensive flood irrigation remained difficult to improve, and combined with outdated irrigation facilities and backward technology, these factors collectively contributed to the current water predicament. Flood irrigation has also triggered large-scale soil salinization, with Uzbekistan' s salinized soil area reaching 2.1$\times$10^{6}$ hm^{2}, ranking it as the sixth largest country in terms of soil salinization. This has caused the salinity of Amu Darya river water to rise to over 1 $g \cdot L^{-1}$, with the salinity of water entering the Aral Sea reaching 10 $g \cdot L^{-1}$ and its water storage shrinking by nearly 1000 km^{3}. Soil salinization and flood irrigation have led to humus loss, reducing cotton yields by approximately 13.1% and creating only about 700 USD in economic value per hectare, causing Uzbekistan to lose about 1.7$\times$10^{8}$ USD annually.

However, systematic elaboration on the relationship between agricultural irrigation and production in Uzbekistan remains limited. This study aims to clarify the development history of irrigated agriculture in Uzbekistan by reviewing historical data on agricultural irrigation area, population, and economic development, and to analyze the causes of a series of environmental problems caused by irrigation agriculture, providing scientific support for agricultural development and water resource management in arid regions.

1.1 Study Area Overview

Uzbekistan is located between 41°16 N and 69°13 E, with a continental climate. It borders Kazakhstan to the northwest, Kyrgyzstan and Tajikistan to the east, Turkmenistan to the south, and the Aral Sea to the north (Figure 1). The terrain slopes from high in the east to low in the west, with plains and lowlands accounting for over 80% of the total area, most of which are located in the Kyzylkum Desert in the northwest. The average annual precipitation in plains and lowlands is approximately 80–200 mm, while mountainous areas can reach 1000 mm. Summer temperatures in plain areas range from 42–47°C, while winter temperatures in the north are about -11°C to -2°C, with most precipitation occurring in spring. Major rivers include the Amu Darya, Syr Darya, and Zeravshan River.

In 2017, Uzbekistan was the most populous country in Central Asia with a total population of 3.2$\times 10^{\{7\},accounting for 45.8\times 10}\{5\}$ km^{2}, representing 11.2% of Central Asia' s total area. It possesses 4.42$\times$10^{6}$ hm^{2} of cultivated land, the highest proportion of farmland area after Kazakhstan, accounting for 11.5% of Central Asia' s total. Its irrigated agriculture contributes about 30% of agricultural output while consuming 90% of the country' s available water resources.

1.2 Research Methods

This study reviewed Chinese and English literature on Uzbekistan' s irrigated agriculture from the past 100 years. Based on the latest data from the Food and Agriculture Organization of the United Nations (FAO), the United Nations Data

Retrieval System, and the State Committee of the Republic of Uzbekistan on Statistics, we summarized changing patterns in irrigated farmland area, population, major crop yields, and agricultural output value. Combined with literature on the study area' s ecological environment and economic development, we 梳理d the development history of irrigated agriculture in Uzbekistan over the past century and analyzed the impacts of irrigated agriculture on the environment and socioeconomic conditions.

2 Development of Irrigated Agriculture and Its Environmental and Socioeconomic Impacts

2.1 Three Stages of Irrigated Agricultural Development

2.1.1 Water Conservancy Infrastructure Construction Stage Irrigated agriculture in what is now Uzbekistan entered its initial stage before the Common Era. By the 8th–7th centuries BCE, the Amu Darya, Zeravshan River, and Kashkadarya River basins in Central Asia had approximately 3.5×10^{5} hm^2 of irrigated farmland. Within the next 200 years, irrigated areas in Central Asia decreased sharply. Until the 10th century, irrigated agriculture gradually revived, and by the 13th century, the total area of the lower reaches of the Amu Darya and Syr Darya rivers reached 2.4×10^{6} hm^2. Before the 15th century, Central Asia reformed its irrigation systems and entered a stage of agricultural water conservancy infrastructure construction, during which numerous narrow and deep channels, high-pressure dams, spillways, and other water supply facilities were built. Modern irrigation technology developed in the Hunger Steppe of the Syr Darya basin in central Uzbekistan and the Karshi Steppe of the Amu Darya basin in the southeast. During this period, Uzbekistan' s irrigation area grew at an average rate of 1.4×10^{4} hm^2 per year, implementing strict water resource management and agricultural irrigation systems. With the reclamation of the Golodnaya Steppe, Jizzakh, and Karshi steppes, irrigated agriculture entered an efficient development stage. By the early 20th century, Uzbekistan had approximately 1.2×10^{6} hm^2 of irrigated farmland.

2.1.2 Rapid Expansion Stage of Irrigation Scale The large-scale development of irrigated agriculture in Uzbekistan began in the late 1950s, when the total irrigated area was about 2.2×10^{6} hm^2. As the Soviet government specially mandated Uzbekistan to specialize in cotton production, the country' s irrigated area gradually expanded, mainly distributed in uninhabited arid and semi-arid areas with harsh climatic conditions. With the development of irrigation technology starting in the 1960s, drainage pipe networks and wells were constructed, initially forming a complete irrigation and drainage system. The main irrigation districts are concentrated in the Tashkent Valley in the northeast, Fergana Valley in the east, Zeravshan Valley in the central-east, Kashkadarya Valley in the southeast, Surkhandarya River basin in the southeast, Khorezm in the northwest, and Karakalpakstan. During this period, Uzbekistan' s irrigated area grew at an average rate of 4.2×10^{4} hm^2 per year. By the 1990s,

2.2×10^{6} hm^2 of new irrigation districts had been developed, bringing the total irrigated area to 10×10^{6} hm^2.

2.1.3 Stagnation Stage of Irrigation Technology Development After the 1990s, the national irrigation area has remained basically stable at 4.2×10^{6} hm^2, accounting for 95% of the total cultivated land area. However, due to reduced area equipped with irrigation facilities, some farmland has been abandoned, with the actual irrigated area being approximately 3.7×10^{6} hm^2. About 42% and 58% are located in the Syr Darya and Amu Darya basins respectively, with irrigated crop yields accounting for 99.9% of total output. With population growth, per capita irrigated area has shown a decreasing trend year by year. All irrigated farmland in Uzbekistan is fully controlled irrigation, with water sources mainly from surface water. River diversion accounts for 84% of irrigation water, while pumping from rivers, reservoirs, and groundwater accounts for 14% and 2% respectively, though the latter pumping methods are relatively extensive. The overall water delivery network relies on approximately 1.96×10^{5} km of canals, of which 80% are unlined earthen channels with low overall conveyance efficiency. Field irrigation technology is also backward, with 99.9% of the land using surface irrigation, of which 67.9% is furrow irrigation, followed by border irrigation (13.1%), flood irrigation (10.5%), and other surface irrigation types (8.5%). More advanced localized irrigation techniques such as sprinkler and drip irrigation have basically lost practical value due to cost increases and insufficient equipment.

2.2 Changes in Agricultural Planting Structure

Uzbekistan has abundant exports of cotton, silk, and hemp products and has traditionally been an important import source for China. In the 1990s, Uzbekistan' s cotton production was only 1.7×10^{6} t, and the Asian Development Bank funded the Amu Darya irrigation renovation project in 1995 to help the South Surkhandarya provincial government improve water resource management capabilities, restore 2×10^{4} hm^2 of farmland and hundreds of kilometers of field drainage canals near the confluence of the Amu Darya and Surkhandarya rivers, and address the livelihood and development issues of approximately 3.3×10^{4} agricultural workers.

Due to geographical constraints, Uzbekistan has difficulty reclaiming new oases, and the total irrigated area has stabilized. To cope with sluggish economic development and urgent food demand, the state actively allocated subsidies to encourage agricultural production. Wheat, which requires less water, gradually replaced cotton as Uzbekistan' s most important crop type. As shown in Figure 4, wheat production in 2020 had increased by 51.3% compared to the early 21st century, demonstrating significant yield increases after planting transformation. However, as cotton planting area continued to decline and environmental problems became increasingly severe, cotton production showed an overall downward trend. On the other hand, when only cotton was planted, the irrigation system could be properly cleaned and maintained during the 2–3 month fallow period from December to February, ensuring cotton yields in non-extreme climate years. Throughout the winter wheat growth cycle, although evapotranspiration is low, 4–5 irrigations are still required. With the substantial increase in planting area, the irrigation and drainage network must operate continuously. Statistics show that irrigated wheat yields are 4400 kg $\cdot$ hm^{-2}, while rain-fed wheat yields are only 1200 kg $\cdot$ hm^{-2}. Therefore, to ensure wheat yields, the irrigation and drainage system operates almost year-round, accelerating equipment depreciation, damage, and leakage losses. Since 2010, the wheat yield growth rate has gradually decreased.

Since 2016, Uzbekistan has gradually shifted farmland planting types from grain to fruits and vegetables to transform its economic structure' s over-reliance on grain production and create more economic benefits within limited land. This has led to continuous reduction in wheat and cotton planting areas and significant yield decreases.

2.3 Environmental Impacts of Irrigated Agriculture

Irrigated agriculture has made Uzbekistan an important agricultural country in Central Asia, but it has also caused enormous impacts on its ecological environment, with water and soil security issues being the most prominent: large-scale soil salinization caused by flood irrigation, strong evaporation, declining irrigation water quality, and high groundwater levels.

2.3.1 Soil Salinization Research by Rakhimbaev et al. on salinized soils in Uzbekistan' s Khorezm region concluded that when groundwater with mineralization exceeding 3 g $\cdot$ L^{-1} has a depth of less than 2.0 m, it can easily trigger salinization. Therefore, Uzbekistan can refer to this method for groundwater management. In the upper reaches of the Aral Sea, groundwater levels can reach critical levels of 1.5 m each spring, limiting the efficiency of early spring farmland leaching. Farmers find it difficult to reduce salt content in soil profiles before planting crops. In August (peak crop growth period), groundwater levels reach their annual minimum, meaning salt content in the soil root zone continues to rise, though irrigation during this period can partially offset shallow soil salt accumulation. Since 2016, changes in national planting structure have introduced large amounts of winter wheat requiring additional irrigation in the later growth stages, causing groundwater levels to show year-on-year increases in August, rising approximately 0.7 m outside the crop growing season.

Uzbekistan has about 2.1$\times10^{6}$ hm^2 of salinized soil, making it the sixth largest country in terms of soil salinization area, causing Amu Darya river water salinity to rise to over 1 g $\cdot$ L^{-1}. The average mineralization of groundwater is maintained at 5.1-10.0 g $\cdot$ L^{-1} in 17.7% of the area, less than 1.0 g $\cdot$ L^{-1} in 29.0% of the area, and fluctuates between 1.1-5.0 g $\cdot$ L^{-1} in the remaining areas. About 51.3% of irrigated land shows varying degrees of salinization. Different soil types respond slightly differently to salinization formation. Moderate and heavy-textured soils, containing more clay particles and having larger capillary porosity, are more prone to soil salinization. For example, the Jizzakh irrigation district, the largest in Central Asia without natural drainage, has applied large amounts of fertilizer to ensure crop yields since 1995, leading to increasingly severe soil salinization. Today, only about 10.5% of cultivated land is non-salinized, while 13.1%, 29.0%, and 47.4% of cultivated land show slight, moderate, and high salinization respectively. In the lower reaches of the Amu Darya and Syr Darya rivers, nearly 80% of the land exceeds salt content standards. Even farmland with healthy soil nutrient background values will input large amounts of salts from high groundwater levels into the soil profile after long-term groundwater irrigation, requiring sufficient water and sound drainage networks for soil salt leaching to prevent soil salinization and reduced farmland productivity. For example, in irrigation districts located in the middle and lower reaches of the Amu Darya, both surface water resources and land resource quality are concerning. Only the Navoi region with complete irrigation and drainage systems shows slight soil salinity improvement.

2.3.2 The Aral Sea Crisis For arid regions far from the ocean, river and lake ecosystems play an irreplaceable role in maintaining human activities and ecological stability within the basin. The Aral Sea, located in northwestern Uzbekistan, was once one of the world' s largest typical inland lakes. In the 1960s, the Aral Sea had an elevation of 53.4 m, water storage exceeding 1000 km^3, and water salinity of 10 $g \cdot L^{-1}$. However, it quickly split into two basins by 1987: the Small Aral Sea in the north and the Large Aral Sea in the south. The drying up of the Aral Sea has exposed large areas of salty sediments and finally formed a new desert (the Aralkum) in 2000, causing frequent salt dust storms that pose serious threats to human respiratory health and the hydrological cycle.

Since the 1960s, 80% of the Aral Sea basin' s runoff has been used for farmland irrigation, significantly reducing water inflow to the sea and causing rapid water level decline. Water storage decreased substantially in 1987, showing significant monthly variation that reflects the lake' s dependence on the current configuration and intensity of farmland irrigation and drainage systems. Surplus water from inefficient agricultural irrigation conversely contributes to the formation of small and medium-sized lakes around the basin. The Aral Sea area shrank from 4.7×10^{6} hm^2 to 1.2×10^{6} hm^2 over the past 40 years, with water salinity increasing threefold compared to 20 years ago. If upstream water diversion for irrigation remains unmanaged, the Aral Sea is projected to completely evaporate and disappear by 2040.

Research by Conrad et al. found that during the crop growing season, lake areas in the lower Amu Darya significantly increase. In 2011, lakes in Khorezm province received 2.4×10^{6} m^3 of agricultural drainage from nearby cultivated land, with winter inflow being 31.4% higher than summer inflow. Studies show that the evolution of Central Asia' s arid climate correlates with evaporation intensity in upstream water bodies like the North Atlantic and Caspian

Sea. After the dissolution of the Soviet Union, grain policy reforms in various countries led to gradual reduction in high water-consumption crops like cotton and rice and increased planting of lower water-consumption crops like wheat, decreasing total agricultural irrigation water demand year by year and gradually restoring river runoff. This demonstrates that transformation in planting structure also helps slow the shrinkage of the Aral Sea basin. However, in 2010, the southern Aral Sea showed decreasing evaporation and increasing precipitation trends, indicating that climate change is not the main driver of long-term Aral Sea shrinkage.

2.3.3 Salt Dust Storms Dust storms are common climatic disasters in arid and semi-arid regions, causing substantial loss of vegetation and surface soil. Their formation is jointly affected by wind force, surface soil stability, and atmospheric conditions. Dust storms with high salt content are specifically termed salt dust storms. Central Asia is covered by over 1.5\$×10^{6}\$ hm^2 of saline soil, with about 80% located in Uzbekistan. As the Aral Sea water area has shrunk year by year, the Aral Sea basin rich in loose sediments has gradually been exposed. From 1985 to 2011, the dried area of the Aral Sea basin increased by 4.5\$×10$^{\{4\}-10\times10}${4}\$ hm^2 annually. The local climate features strong winds, sparse vegetation, and long drought periods, making salt dust storm frequency much higher than in other regions. Each year, 4.5\$×10$^{\{5\}-10\times10}${5}\$ tons of salt-containing dust is blown from the Aral Sea basin into the atmosphere, traveling as far as thousands of kilometers to the Himalayas, Antarctic ice sheets, Greenland glaciers, Norwegian forests, and Belarusian farmland, affecting vegetation growth and human respiratory system health. Salt dust storms have even more significant impacts on the hydrological cycle. Containing large amounts of chloride salts, they inevitably accelerate snowmelt rates in surrounding snow-capped mountains, disrupting downstream ecological balance of rivers and oases. This feedback relationship is naturally more sensitive in the arid Central Asian region.

For millions of years, the Aral Sea riverbed continuously absorbed salt substances from the basin and pesticides and herbicides from farmland drainage. The now annually expanding dry riverbed has become an important source of local dust and salt aerosols. During the 1950s–1980s, the rapid development period of Uzbekistan' s irrigated agriculture, large areas of forest and pasture were converted to farmland, substantially reducing land' s windbreak and sand fixation capacity. Meanwhile, some runoff from the Amu Darya and Syr Darya rivers was diverted to surrounding farmland for irrigation, gradually exposing river and downstream Aral Sea beds. In 2000, the exposed loose sand at the bottom of the Aral Sea became a potential source point for salt dust storms. Additionally, reduced total surface water volume warmed the surface and increased boundary layer instability, also favoring dust storm formation and vertical transport of dust particles. This indicates the coupling relationship between precipitation, clouds, and soil moisture within the Aral Sea basin, providing potential conditions for salt dust storm formation, which aligns with conclusions from early studies on the Aral Sea' s environmental crisis. During this period, salt dust storm frequency near the Karakum Desert, Central Asia' s largest desert, exceeded 80 days per year, while during the same period, the Naryn region in the Caspian Sea' s northern lowlands and the Kyzylkum Desert in the Volga-Ural region showed moderate salt dust storm frequency of about 20–30 days per year. As various regions successively reclaimed land for cultivation, desert areas were gradually replaced by farmland, and exposed loose surface dust was somewhat controlled, leading to an overall reduction in salt dust storm frequency. However, the Aral Sea region and some desert centers like the Karakum Desert, lacking long-term water resource supply and featuring windy arid continental climate conditions and fine-grained soil, still exhibit high outbreak frequencies of 40 days per year. This demonstrates that the existence and scale of desert environments are key factors affecting frequent salt dust storm outbreaks.

2.4 Relationship Between Irrigated Agriculture and National Socioeconomic Development

As a typical agricultural country, Uzbekistan' s agriculture is an important economic pillar, contributing about 30% of GDP and providing 28% of national employment. Comparing the growth rates of Uzbekistan' s GDP, agriculture, industry, and service sectors since the 21st century (Figure 6) reveals that Uzbekistan' s total population has steadily increased, showing faster growth after 2008, representing more labor force but also meaning greater food demand. Gross domestic product has also grown steadily year by year, with an average annual growth rate maintained at 5%–8%. Among the three major industries, agricultural output value shows high consistency with GDP trends. When agriculture develops rapidly, GDP grows quickly; when agricultural development is hindered, GDP growth slows. This indicates that Uzbekistan' s agricultural development determines GDP trends to a certain extent, and this dependency is so close that it can mitigate the impact of small fluctuations in industrial or service sector output values.

Like other republics of the former Soviet Union, Uzbekistan' s traditional agriculture was managed under a dual system of collective farms and state farms. During the last decades of the Soviet era, although household plots accounted for only 11.5% of total cultivated land, their surplus productivity enabled farmers to sell large quantities of products to the state cooperative system, creating 20%–25% of Uzbekistan's agricultural production value, far exceeding their land share. This was partly because Uzbekistan' s concentrated and complete livestock production system could generate substantial economic income, and partly because household plots mostly grew high-economic-value crops like potatoes, vegetables, and fruits, whose total output accounted for 51.3%, 29.0%, and 47.4% of national production respectively, while capital-intensive and mechanized scale crops like cotton and grain were mainly planted by collective and state farms.

In 1991, Uzbekistan introduced a new Land Law that increased the upper limit of irrigated area and distributed more cultivated land to residents, causing the total area of household plots to increase from 2.5×10^{4} hm^2 to 2.1×10^{6} hm^2 within a few years. However, lease contracts stipulated that each piece of land contracted from the state must guarantee minimum sowing areas for cotton and wheat. The 1998 Farmers' Farm Law further required that leased land be diligently cultivated to achieve minimum harvest yields for cotton and wheat. Combined with the agricultural planting structure transformation trend discussed in Section 2.2, it can be found that national wheat and cotton total output grew rapidly in the early 21st century, causing Uzbekistan' s agricultural output value to reach a peak of 5.9×10^{10} USD in 2016. As the scale of irrigated agriculture continued to expand, the irrigation and drainage network operated beyond capacity, ultimately leading to reduced water delivery efficiency and slower wheat yield growth rates. However, due to extremely scarce water resources and food gaps, planting types had to continue shifting toward wheat with lower water consumption and higher yields, further increasing pressure on the irrigation and drainage system and gradually forming a difficult-to-break vicious cycle. Research by Bobojonov et al. on sustainable agricultural development in arid regions shows that inefficient irrigation in dryland areas cannot cope with natural and anthropogenic water shortages, and shifting from cotton and rice to less water-demanding crops can alleviate water supply instability impacts. Furthermore, urgent government investment in technology and financial subsidies is needed to promote more efficient irrigation technologies to fundamentally solve future water shortage problems.

In 2017, the Uzbekistan government established a special fund for infrastructure improvement. With the implementation of inspection and maintenance work, drainage canals in dryland farmland in Bukhara, Kashkadarya, and Fergana have been restored to some extent, wheat yields have improved, and the maximum value was reached in 2019, accounting for 80% of national grain production during the same period and becoming the most important component of agricultural output value, causing the total agricultural economy to rebound to 5.9×10^{10} USD. Although the irrigated area showed slight growth in 2020, affected by the transformation of crop types, agricultural output value growth rate slightly decreased synchronously with wheat yields and remained at 5%-7%.

3 Conclusions

This study, based on the 梳理 of Uzbekistan' s agricultural irrigation, population, and economic data, summarizes the impacts of irrigated agricultural development on regional environment and socioeconomic conditions, providing scientific reference value for agricultural development and water resource management in arid regions. The main conclusions are as follows:

(1) As a typical agricultural country in arid regions, Uzbekistan' s agricultural output value is an important economic source, creating about 30% of gross domestic product and exerting a significant positive impact on GDP. Its

irrigated agriculture has been developing steadily with great potential.

(2) The main crops have gradually transitioned from cotton to winter wheat, which not only failed to alleviate agricultural water tension but instead aggravated water resource loss. Addressing this problem requires fundamentally optimizing farmland irrigation and drainage technology, such as large-scale implementation of advanced and efficient irrigation and drainage methods including drip irrigation, sprinkler irrigation, and subsurface pipe salt drainage.

(3) Uzbekistan' s agricultural irrigation water mainly comes from river diversion, causing significant decline in downstream Aral Sea water storage and triggering environmental problems such as soil salinization, increasing mineralization of river and lake water, and salt dust storms that destroy local hydrological cycle processes.

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