Study on Water Resources Allocation in an Irrigation District from the Perspective of Supply and Demand

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Abstract: According to the conditions of water resources and development and utilization in the irrigated area, the agricultural water demand, domestic water demand, industrial water demand and ecological water demand in the irrigated area were analyzed and predicted, and the water resources were allocated through the analysis of supply and demand balance, which provided theoretical basis for the construction and operation of irrigated area.

1. Basic information of the project

1.1 Project background

According to the spirit of the central government' decision on accelerating the reform and development of water conservancy, to improve the local agricultural irrigation quality and water use efficiency and guarantee rate, reduce groundwater exploitation, it is planned to launch irrigation water source projects in the irrigated area to keep the river water level at a high level and alleviate the shortage of irrigation water. The planning irrigated area of the projects is 94,000 mu, and the designed irrigation guarantee rate is 75%.

1.2 Prediction of water demand in the irrigated area

It is planning that in 2030, the total water demand will be 37.942 million m^3, including 5.57 million $m^3$for domestic use, 11.001 million m^3 for industrial use, 20.714 million m^3 for agricultural irrigation and 657,000 m^3 for ecological use.

1.3 Available water supply

It is planning that in 2030, the available water supply of P=75% year will reach 5.805 million m^3. The multi-year average transit water amount of the river channel will reach 126 million m^3, and the transit water amount of P=75% year will be 39 million m^3. There is a planning rubber dam with a water level of 82.5m (dead water level of 76.5m), a total water storage capacity of 6.01 million m^3 and a benefit storage capacity of 4.91 million m^3. After the completion, the rubber dam can maintain the upstream water level at a high level to adjust the runoff in dry season, thus ensuring the water intake in the irrigated areas.

2. Water resources conditions

2.1 Regional water resources

(1) Local surface water resources

Water resources exploration requires to comprehensively consider multiple factors and adopt various suitable methods [1]. The local surface runoff in the irrigated area mainly comes from heavy rainfall in flood season, and it is difficult to form runoff in non-flood season due to less rainfall [2,3]. Therefore, the annual runoff is mainly concentrated in flood season, and the rainstorm from July to September often forms most of the annual runoff, and the annual distribution of runoff is extremely uneven. The amount of local surface water resources in the irrigated area is calculated according to its control area and runoff depth. The multi-year average runoff depth in the irrigated area is 142.0mm, and the runoff depth in the year of P=75% is 116.4mm, so the multi-year average amount of local

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surface water resources in the irrigated area are 17.703 million m³, and the amount of local surface water resources of P=75% year is 14.512 million m³.

(2) Groundwater resources

The amount of groundwater resources refers to the dynamic amount of groundwater that can be renewed and participates in the water cycle, and its main recharge sources include precipitation infiltration, river leakage, reservoir and pond leakage, and irrigation water return (excluding the return amount of well irrigation) [4]. Water resources include natural reserves and regulated reserves [5].

Groundwater resources are mainly influenced by hydrometeorology, topography, hydrogeology, vegetation, water conservancy projects and other factors. Their regional distribution are generally expressed by modulus, and the total amount is calculated by the total recharge modulus of groundwater. Since the total recharge modulus of groundwater in the irrigated area is 150,000 m^3/km^2, the amount of groundwater resources in the irrigated area is 18.701 million m³.

(3) Total water resources

The multi-year average of water resources in the irrigated area is 36.404 million m³ without deducting the repeated calculation of water resources, and is 32.864 million m³ after deducting the repeated amount. That of P=75% is 33.213 million m³ without deducting the repeated calculation of water resources, and is 30.31 million m³ after deducting the repeated amount.

(4) Transit water quantity

The river flows through this irrigated area from northwest to southeast. The river originates from Shenpo Village, Dengfeng City, the eastern foot of Funiu Mountain Range. It flows through Yuzhou, Xiangcheng, Xuchang, Linying, Yancheng, Fugou, Xihua and other counties and cities, and finally flows into Shahe River at Sunzui near Zhoukou City, with a total length of about 263km and a drainage area of 7348km^2. Yingqiao Hydrological Station is located in the irrigated area, with a control area of 1910km^2; there is a Huaxingzha Hydrological Station downstream, with a catchment area of 1912km^2. According to the results of hydrological analysis, the average annual transit water amount of the river in the planning range is 126 million m³, and the transit water amounts at different frequencies are shown in Table 1.

Table 1 Transit water amounts of the river at different frequencies within the planning scope

Design values of different frequencies (unit: 100 million m³)				
Average (hundred million m³)	20%	50%	75%	95%
1.26	1.91	0.77	0.39	0.26

2.2 Status of water resources development and utilization

(1) Status of surface water development

Most of the channels in the irrigated area are seasonal rivers. There is water in the flood season, but there is basically no water at other times. Because there is no irrigation water supply task in the flood season, and there is a lack of water source regulation and storage projects and corresponding supporting projects in the irrigated area, the development and utilization rate of local surface water resources in the irrigated area is extremely low.

(2) Development and utilization rate of groundwater

The surface water resources in the irrigated area are scarce and difficult to use. The industrial and agricultural water in the irrigated area mainly depends on the exploitation of groundwater. However, due to the large exploitation of groundwater, the groundwater level generally drops. In the drought year, it is difficult to ensure water for production and domestic water for people and animals.

2.3 Available water resources

(1) Available amount of surface water

The available amount of surface water refers to the one-time maximum amount of water that can be used through economically reasonable and technically feasible measures in the foreseeable period, on the basis of overall consideration of social and economic water use and ecological environment water use in the irrigated area, and coordination of water use inside and outside regional rivers [6].

The available amount of surface water in the irrigated area is calculated by the available coefficient method. Since the available coefficient of surface water resources in this area is 0.40, the multi-year average available amount of surface water in the irrigated area is 7.081 million m^3, and the available amount of surface water of P=75% year is 5.805 million m^3.

(2) The exploitable amount of groundwater

The exploitable amount of groundwater refers to the maximum amount of water that can be obtained from the groundwater aquifer in the foreseeable period through economically reasonable and technically feasible measures without causing the deterioration of the ecological environment.

The exploitable amount of groundwater in the irrigated area is determined by the exploitation coefficient method. Since the exploitation coefficient is set at 0.80, the multi-year average exploitable amount of groundwater in the irrigated area is 14.961 million m^3.

(3) The total available amount of local water resources

The multi-year average amount of available water resources in the irrigated area is 22.042 million m^3 without reducing repeated calculation, and it is 20.626 million m^3 after reducing the repeated amount; the amount of P=75% year total available water resources is 20.765 million m^3 with repeated calculation, and is 19.604 million m^3 after reducing the repeated amount.

3. Prediction of water demand in the irrigation area

3.1 water demand of agricultural irrigation

(1) Design irrigation guarantee rate

The irrigated area is located in the semi-arid and semi-humid area of the eastern Henan plain, and is mainly used for planting dry crops. According to the *Design Standard for Irrigation and Drainage Engineering* (GB50288-2018), in semi-arid and semi-humid areas, the designed irrigation guarantee rate is 70%-80% when mainly planting dry crops [7]. The planning irrigation guarantee rate of the irrigated area is 75%.

(2) Design of irrigation system

Based on the evaporation and rainfall data from Xiangcheng Station, the irrigation system of main crops over the years was determined by using the time calendar through field investigation and referring to the field irrigation test data. Crop water demand is the main basis for designing irrigation system. The reference crop evapotranspiration was calculated by Penman method, and then it was corrected to the actual crop water demand according to crop types and soil factors.

At any time of the crop growth period, a certain amount of water storage (i.e., soil water content) must be maintained in the planning wetting layer of soil to meet the normal growth and development needs of crops. Through the water balance calculation of the water storage in the planning layer, the time and water quantity of supplementary irrigation can be obtained, and the irrigation system can be established. The basic formula of water balance is:

$$W_T-W_O=W_P+P_O+K+M-E$$

Wherein:

W_T: water storage in the final wetting layer during the calculation period;

W_O: water storage in the initial wetting layer in the planning period;

W_P: the increased water storage capacity due to the increase of planning soil layer;

P_O: effective rainfall during the calculation period;

K: groundwater recharge;

M: amount of supplementary irrigation water during the calculation period;

E: water demand of crops during the calculation period.

Through the frequency calculation and line fitting analysis of 58-year series data in the irrigated area, it is determined that the year type of P=75% is 1989. According to the formula of water balance, the irrigation schedule of three representative crops of P=75% year, namely wheat, tobacco and corn, is calculated every ten days, and the irrigation norm, irrigation times and irrigation time of the main crops in the irrigated area are obtained.

In this irrigation system design, the water-saving irrigation system of “hallow wetting interval and

deep storage after rain" was adopted. According to the rainfall in each growth period and the planting proportion of each crop, the annual comprehensive irrigation net quota of P=75% year was obtained. After considering the improvement of crop species, the progress of irrigation system and the popularization of water-saving measures, it is calculated that the comprehensive net irrigation norm of P=75% year in the irrigated area in 2030 is 154.3m³/ mu. Considering the low water utilization coefficient of canal system in the irrigated area, according to the requirements of the strictest water resources management system and water-saving society construction gradually implemented by China, and combined with the calculated results of canal system utilization coefficient in special planning of the irrigated area, it is planning that the water utilization coefficient of canal system in the irrigated area in 2030 is 0.7, and the comprehensive gross irrigation norm of P=75% year will be 220.4m³/ mu.

(3) Design irrigation rate

The irrigation rate depends on the composition of crops, irrigation norm and irrigation duration [3]. In this study, the irrigation system of P=75% year was used as the design irrigation system. The irrigation rate of the irrigated area was calculated according to the following formula and the irrigation rate map was drawn. See Table 2 and Figure 1 for the preliminary results of irrigation rate.

Irrigation rate calculation formula:

$$q = \frac{\alpha m}{0.36Tt}$$

Wherein:

q: irrigation rate of a certain crop (m³/s ten thousand mu);

α: planting proportion of a certain crop;

T: duration of secondary irrigation (day and night);

M: irrigation norm of a certain crop (m³/mu).

Table 2 Preliminary results of irrigation rate in the irrigated area

Crop	Irrigation norm	Irrigation times	Irrigation time	Growth stage	Irrigation norm	Duration	Irrigation norm
Wheat	125	3	2.11-2.19	Overwintering	40	8	0.260
			3.20-3.27	Jointing	45	8	0.293
			5.1-5.8	Head sprouting	40	8	0.260
Corn	65	2	7.11-7.15	Jointing	30	5	0.313
			8.21-8.27	Grouting	35	7	0.260
Tobacco leaf	125	3	5.15-5.22	Delayed growing stage	40	8	0.318
			6.1-6.9	Vigorous growing stage	40	9	0.283
			6.20-6.28	Vigorous growing stage	45	9	0.318

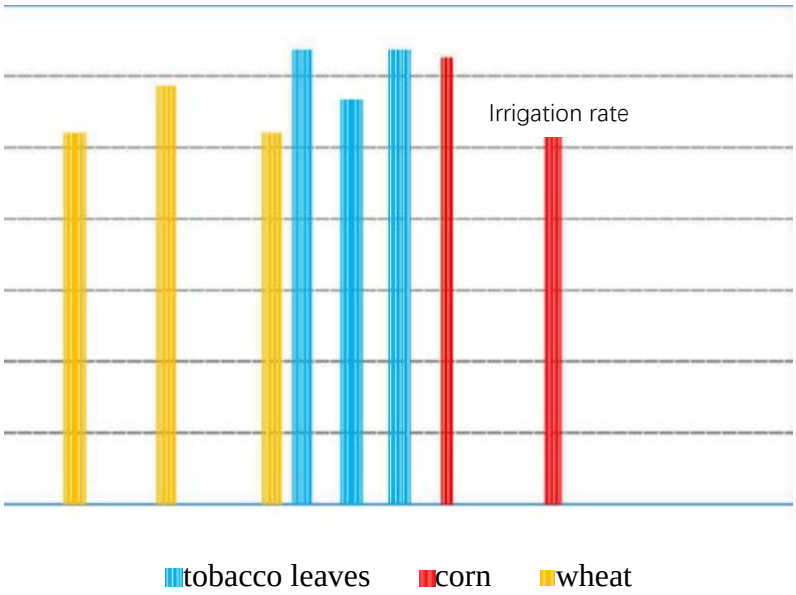

Figure 1 Preliminary results of irrigation rate in the irrigated area

According to the requirements of *Design Standard for Irrigation and Drainage Engineering* (GB50288-2018), the irrigation time was corrected, and the representative annual irrigation rate chart was drawn. See Table 3 and Figure 2 for the irrigation rate correction results. The design irrigation rate of the irrigated area is 0.318 m³/s·ten thousand mu.

Table 3 Results of irrigation rate correction in the irrigated area

Crop	Irrigation norm	Irrigation times	Irrigation time	Growth stage	Irrigation norm	Duration	Irrigation rate	Planting proportion
Wheat	125	3	2.13-2.19	Overwintering	40	7	0.298	0.45
			3.20-3.27	Jointing	45	8	0.293	0.45
			5.1-5.7	Head sprouting	40	7	0.298	0.45
Corn	65	2	7.11-7.15	Jointing	30	5	0.313	0.45
			8.21-8.26	Grouting	35	6	0.304	0.45
Tobacco leaf	125	3	5.13-5.20	Delayed growing stage	40	8	0.318	0.55
			6.1-6.9	Vigorous growing stage	40	9	0.283	0.55
			6.21-6.29	Vigorous growing stage	45	9	0.318	0.55

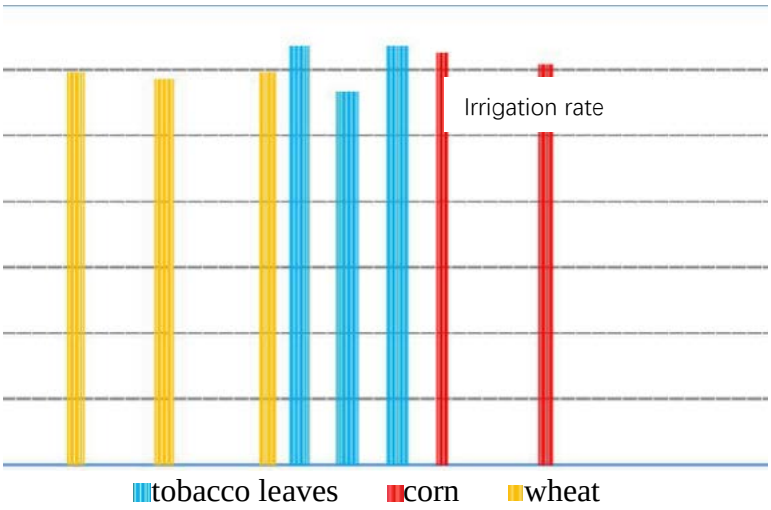

Figure 2 Results after irrigation rate correction in the irrigated area

(4) Prediction of water demand of agricultural irrigation

According to the comprehensive gross water demand quota of P=75% year of the irrigated area calculated in the previous section, the net water demand of agricultural irrigation in the irrigated area in 2030 is 14.50 million m³, and the gross water demand of irrigation is 20.714 million m³.

3.2 Domestic water demand

(1) Urban residents' domestic water demand

Urban domestic water demand includes urban residents' domestic water demand and urban public water demand.

In 2021, the quota of urban domestic water demand in the planning area is 106.6 liters/person-day. According to the analysis of the present situation and future growth trend of residents' domestic water demand in the irrigated area, and considering the continuous improvement of water-saving measures in the planning level year in the future, it is predicted that the quota of urban domestic water demand in the planning irrigated area in 2030 will be 125 liters/person-day. Then, in 2030, the urban domestic water demand in the irrigated area will be 2.133 million m³.

(2) Rural domestic water demand

Rural domestic water demand includes domestic water for rural residents and livestock.

In 2021, the domestic water demand quota of rural residents in the planning area is 62.4 liters/person-day. According to the analysis of the current situation and future growth trend of domestic water demand of residents in the irrigated area, and considering the continuous improvement of water-saving measures in the planning level year in the future, it is predicted that the domestic water demand quota of rural residents in the planning irrigated area will be 70 liters/person-day in 2030. Referring to the results of *Comprehensive Planning of Water Resources in Huaihe River Basin*, it is predicted that the water demand quota of large and small livestock in the irrigated area in 2030 will be 50liters/ head-day and 20L/ head-day, respectively.

It is predicted that in 2030, the rural domestic water demand will be 3.438 million m³, including 2.168 million m³ for rural residents and 1.27 million m³ for livestock.

3.3 Industrial water demand

In 2021, the water demand of industrial added value of RMB 10,000 in the irrigated area is 30.8 m³. According to the present industrial water consumption in the irrigated area and referring to the results of *Comprehensive Planning of Water Resources in Huaihe River Basin*, it is predicted that the water demand of industrial added value of RMB 10,000 in the irrigated area in 2030 will be 18.0 m³; in 2030, the industrial water demand in the planning area will be 11.001 million m³.

3.4 Ecological water demand

The ecological water demand outside the river is mainly for greening water, environmental

sanitation water and river and lake water supplement. Among them, the greening water and environmental sanitation water are calculated according to the greening area of the built-up area; the river landscape water is divided into two parts. One part is to supplement the evaporation loss of water surface. The other part is to change the water quantity of rivers and lakes, which is mainly affected by the water storage capacity and water storage process of rivers and lakes.

In 2030, the ecological water demand outside the river in the irrigated area will reach 657,000 m³.

3.5 Total water demand

As shown in Table 4, the planning total water demand in 2030 is 37.942 million m³. Among it, the domestic water demand is 5.57 million m³, accounting for 14.7% of the total water demand. The industrial water demand is 11.001 million m³, accounting for 29.0% of the total water demand; the agricultural irrigation water demand is 20.714 million m³, accounting for 54.6% of the total water demand; the ecological water demand is 657,000 m³, accounting for 1.7% of the total water demand.

Table 4 Total water demand of the irrigated area in the target year of planning

	Life	Industry	Irrigation	Ecology	Total
water demand	557.0	1100.1	2071.4	65.7	3794.2
Proportion of	14.7%	29.0%	54.6%	1.7%	100.0%

See Figure 3 for the process of water demand in the irrigated area.

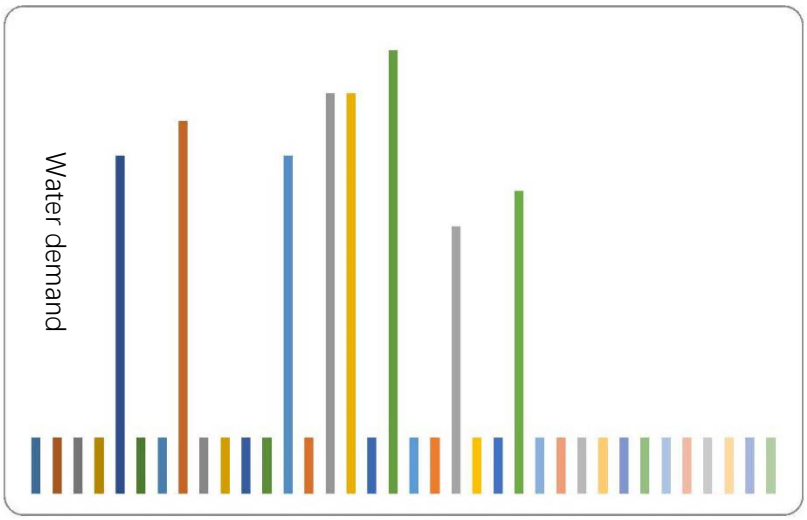

Figure 3 Process diagram of annual water demand in the irrigated area

4. Available water supply

4.1 Local water resources

(1) Local surface water

The local surface water resources in the irrigated area are scarce. By 2030, after the completion of the diversion canal system in the irrigated area, the available surface water resources of P=75% year will reach 5.805m³.

(2) Local groundwater

At present, the main water source in the planning scope is local groundwater. From the perspective of water resources protection and sustainable utilization, it is predicted that the available groundwater supply will reach 14.961 million m³ in 2030.

(3) Total available water supply of local water resources

In 2030, the total available water supply of local water resources of P=75% year is 19.604 million m³.

4.2 River diversion

The multi-year average transit water amount of the river is 126 million m³, and the transit water amount of P=75% year is 39 million m³. It is planned to build a rubber dam with a water level of 82.5m (dead water level of 76.5m), a total water storage capacity of 6.01 million m³ and a benefit storage capacity of 4.91 million m³. After the completion, the rubber dam can maintain the upstream water level at a high level to adjust the runoff in dry season, thus ensuring the water intake in the irrigated areas.

5. Supply and demand analysis and water resources allocation

5.1 Supply and demand analysis principle

(1) The supply and demand analysis is calculated by the typical year method, and the calculation period is ten days;

(2) Through the joint regulation of local surface water, local groundwater and river diversion, the rationality of water use in each water use unit in the irrigated area in space and time can be met;

(3) The guarantee rates of urban domestic water, industrial water and ecological water outside the river are all 95%, and the guarantee rate of agricultural irrigation water is 75%.

(4) Local groundwater is preferred for urban domestic water in the irrigated area; local groundwater is used for industrial water, and the industrial water is diverted from the river channel when the groundwater insufficient; local surface water is preferred for ecological water, and groundwater is used for supplement when the local surface water is insufficient; for farmland irrigation, local surface water is preferred. Local groundwater is used in case of shortage, and river diversion is finally adopted.

5.2 Analysis of supply and demand in the planning year

In 2030, the total water demand of the irrigated area is 37.942 million m³, including: domestic water demand of 5.57 million m³, industrial water demand of 11.001 million m³, farmland irrigation water demand of 20.714 million m³ and ecological water demand of 657 thousand m³.

According to the analysis and calculation, the total water supply in the irrigated area in 2030 is 37.238 million m³, including: local surface water supply of 3.956 million m³, groundwater supply of 13.8 million m³ and river diversion of 19.482 million m³.

In 2030, the total water shortage in the irrigated area is 703,000 m³, and the water shortage rate is about 3.4%. The supply and demand of water resources in the irrigated area are basically balanced.

5.3 Water resources allocation in the planning year

(1) Allocation according to users

In 2030, the urban domestic water, industrial water, agricultural irrigation water and ecological water in the irrigated area will reach 5.57 million m³, 11.001 million m³, 20.01 million m³ and 657,000 m³ respectively, with a total water consumption of 37.238 million m³.

(2) Allocation according to water resources

In the irrigated area in 2030, the local surface water supply, the groundwater supply, and the river diversion will reach 3.956 million m³, 13.8 million m³ and 19.482 million m³ respectively, with a total water supply of 37.238 million m³.

6. Conclusions

(1) Irrigation area

According to the analysis and calculation of water balance in the irrigated area, under the condition of making full use of local water resources and river water, the regulation and storage function of the constructed rubber dam can basically meet the water demand of users in the irrigated area of 94,000 mu.

(2) Quantity of water diversion from the river

The quantity of water diversion from the river in the irrigated area is 19.482 million m³. All of the water is used for farmland irrigation in the irrigated area.

(3) Utilizable capacity

According to the ten-day runoff process and ten-day water consumption process at the proposed rubber dam, after the completion of the rubber dam, the water level can reach 82.5m in January, early February, early March, May, middle and late September, October, November and December. The total storage capacity can reach 6.01 million m^3 and the utilizable capacity can reach 4.23 million m^3.

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