Study on Irrigation Pattern in Irrigation Area of Semi-arid Region

Zijia Dong*
School of Business, Hofstra University, New York, United states
*Corresponding author: Zdong3@pride.hofstra.edu

Abstract. This paper takes 75% precipitation guarantee rate of Taoer River irrigation area in semi-arid area as an example, establishes the economic loss accounting model of irrigation area, studies the predicament of water resources allocation in irrigation area and the economic profit and loss under different irrigation modes in irrigation area. This paper discusses irrigation mode and transition development path. The study shows that in the dry year of 75% precipitation guarantee rate, adjusting the irrigation area diversion plan to make the region III into full surface water irrigation can reduce the loss of 26.23 million yuan. Although the region I and region II groundwater single irrigation than mixed irrigation model loss of 23.33 million yuan, but the development of paddy field to dry field soybean and water-saving total income can increase 1.99128 million yuan. Therefore, under the background of climate change, adjusting the water diversion plan of irrigation area and changing groundwater to dry field will be the transformation and development direction of irrigation area in semi-arid area.

Keywords: Irrigation model, Semi-arid region, Economic gains and losses, Taoer River Irrigation District.

1. Introduction
Climate change has become an important factor affecting water and food production in agriculture [1-3], which result in an increase of over 100 billion cubic meter (m³) in the average amount of water used for irrigation [3, 4]. As an important strategy to realize the sustainable utilization of water resources and the sustainable development of national economy, irrigation district has made an important contribution to ensuring the food security of our country. However, with the aggravation of global climate change, the distribution of water in time and space is not uniform. Although the water is abundant in abundant years, the lack of water in dry years has affected the normal development of irrigation areas. In this paper, the situation of water shortage in irrigation area in dry year due to the aggravation of climate change is studied. This problem has been concerned and studied by many scholars, Feng Lianhong [5]. This paper analyzes the present situation of irrigation area, points out the restrictive factors of irrigation area development, and puts forward the need to change ideas and scientific planning to promote the development of irrigation area to intensive and efficient agriculture. Qi Xuebin [6]. This paper studies and analyzes the rational allocation of water resources in irrigation areas, and puts forward relevant suggestions according to the problems existing in the allocation of water resources in domestic irrigation areas. Zhang Zhanyu [7] considering the characteristics of large
system of water resources and land resources, the optimal allocation model of agricultural soil and water resources in water shortage irrigation area is established with the maximum net income of irrigation area as the goal. Han Lu et al [8] based on the Jensen model, combined with crop irrigation area and market price, the model of water supply and water supply ratio to crop economic benefit is constructed.

Based on the previous research results, this paper selects Taoer River Irrigation District in semi-arid area as the research object, analyzes the dilemma of water resources allocation in irrigation area and the economic profit and loss under different irrigation modes in 75% precipitation guarantee rate year, and puts forward some suggestions for the transformation and development of semi-arid irrigation area under the condition of water shortage.

2. Study Zone
Taoer River Irrigation District of Jilin Province is located in Baicheng City, Jilin Province, southwest of Songnen Plain in the lower reaches of Taoer River. It is a large irrigation area that the country began to build in 1993. Taoer River upstream Charsen Reservoir supporting project. Taoer River alluvial plain agricultural comprehensive development of water projects, Baicheng City to change the ecological environment, rich well-off and build a new socialist countryside hope project. At present, the project of continuous construction and water saving reconstruction in Taorhe Irrigation District is included in the key project planning of increasing production of 10 billion catties of commercial grain in Jilin Province.

And the planned irrigation area of Taoer River irrigation area is $3.79 \times 10^4$ ha. By Taoer River Irrigation District Administration for irrigation management. According to the irrigation plan of Taoer River Irrigation District Administration Bureau, 75% of the precipitation guarantee rate years, Taoer River Irrigation District from April to September from Taoer River diversion, the total annual water diversion is about $3.06 \times 10^8$ m$^3$. The monthly water diversion is shown in Figure 1.

![Figure 1. Water diversion from Taoer River Irrigation District.](image)

Taoer River Irrigation District is designed as a multi-channel diversion mode, which is mainly surface water, supplemented by groundwater. It is a well-channel combined irrigation area with surface water and groundwater complementary and combined allocation. It shoulders the farmland water supply task of 28 townships (towns and fields) in 6 counties (cities, districts, fields) of Taonan, Da’an and Zhitaer River Farm and Zhennan Sheep Farm.
In the year of 75% precipitation guarantee rate, the natural water inflow of Taoer River in semi-arid area is insufficient, which can not meet the water diversion plan of Taoer River Irrigation area while ensuring its own ecological water demand. Taoer River Irrigation District in May-September has varying degrees of water shortage, see Figure 2 for details.

![Figure 2. Water shortage rate per month in Taoer River Irrigation District.](image)

Due to the serious water shortage in the normal growth month of rice in Taoer River Irrigation District, it is faced with huge economic loss and yield crisis. It can be seen that the transformation of irrigation area has become an important solution to alleviate the shortage of water resources in Taoer River Irrigation District.

3. Methodology and Data Sources

3.1. Model approach

According to the difference of irrigation water quality, there are three irrigation modes: total surface water irrigation, surface water and groundwater mixed irrigation, and groundwater single irrigation. Based on the whole surface water irrigation, the economic loss accounting model of Taoer River irrigation area is constructed under the condition of insufficient surface water supply in Taoer River irrigation area. The economic loss of Taoer River Irrigation District includes the loss of farmers and the loss of Irrigation District Administration Bureau. In this paper, we only consider the loss of farmers in irrigation area and subdivide the loss of farmers in irrigation area into four aspects: the loss of crop reduction in wellhead, the loss of crop reduction, the loss of agricultural product quality and the increase of irrigation cost of well water [9].

3.1.1. Loss of crop production based on wellhead. Well water irrigation will be affected by the erosion of irrigation near the wellhead and the low water temperature. Nearly 0.2 mu of wellhead field per hectare does not produce rice or seriously reduces production. This part of the loss can be expressed by the following formula 1:

\[ L_s = \delta \times S \times Q_s \times P_s \times D \]  

(1)

\( L_s \) represents the loss of crop production at the wellhead (yuan); \( \delta \) is adjustment coefficient of crop production reduction at the wellhead; \( S \) is irrigation area paddy field area (hm²); \( Q_s \) is under the
condition of surface water irrigation, the yield per unit area of crops (kg); is the unit market value of
crops under the condition of surface water irrigation. D is water shortage rate of irrigation area.

3.1.2. Losses based on crop reduction. Because the water quality of well water is not good and the
water temperature is low, the unit yield of rice decreases and the income of farmers decreases. This
part of the loss can be expressed by the following formula:

\[ L_2 = \left( Q_s - Q_g \right) \times P_s \times S \times D \]  \hspace{1cm} (2)

\( L_2 \) is the loss of crop production (yuan); \( Q_g \) represents groundwater irrigation, crop yield per unit
area (yuan/kg).

3.1.3. Losses based on declining quality of agricultural products. The quality of rice is greatly
reduced because the water temperature of well water irrigation increases the slow seedling stage
during seedling transplanting, which is mainly reflected in the decrease of market price. This part of
the loss can be expressed by the following formula:

\[ L_3 = Q_s \times \left( P_s - P_g \right) \times S \times D \left[ 1 - \frac{Q_s - Q_g}{Q_s} \right] \]  \hspace{1cm} (3)

\( L_3 \) is the loss of the quality of agricultural products (yuan); represents groundwater irrigation, the
unit market value of crops (yuan/kg).

3.1.4. Losses based on increased water costs. This part of the loss can be expressed by the following
formula:

\[ L_4 = (C_s - C_g) \times S \times D \]  \hspace{1cm} (4)

\( L_4 \) is the loss of the increase in the cost of water supply; \( C_g \) is the cost of using unit groundwater for
farmers in irrigation areas (yuan/m³); \( C_s \) cost of using unit surface water for irrigation farmers
(yuan/m³).

3.1.5. Total loss in irrigation areas. To sum up, the total loss of irrigation area can be expressed as:

\[ L = \sum_{i=1}^{4} L_i \]  \hspace{1cm} (5)

\( L \) is the total loss of irrigation area, \( i \) is the type of loss, and the value of \( i \) is 1, 2, 3 and 4.

3.2. Data sources
There are four main aspects of the reference source. (1) Partial data obtained from the Baicheng
Statistical Yearbook. (2) Part of the data obtained from the Baicheng Water Resources Bulletin. (3)
Part of the data provided by Taoer River Irrigation District. Part of the data is from Water
Consumption and Water Deficiency of Main Crops in Three Northeast Provinces by Yin Zhiqiang [10].

For the convenience of calculation and case description, the planned irrigation area of Taoer River
Irrigation District is \( 3.79 \times 10^4 \) hectares are regarded as paddy fields, which will produce errors in
calculation, but will not affect the overall research results of this paper.
| Crop Type | Maximum per hectare m water consumption | Output per unit area/(kg·hm\(^{-2}\)) | Unit price/(Yuan kg) Fiscal year: 2003\(^{-1}\) | hm per unit area\(^{2}\) |
|-----------|----------------------------------------|----------------------------------------|--------------------------------------------|-----------------|
| Rice      | 9983                                   | 7554                                   | 3                                         | 22662           |
| Corn      | 7269                                   | 5249                                   | 2                                         | 10498           |
| Soybean   | 8867                                   | 2338                                   | 4.8                                       | 11222           |

4. Analysis of Irrigation Pattern and Profit and Loss Relationship in Irrigation Area

4.1. Analysis of irrigation patterns in irrigation areas

The amount of water drawn from Taoer River in irrigation area needs to be transported to all parts of irrigation area through water conveyance canal. The farther the transportation distance is, the more serious the water loss is. When the water quantity is insufficient, it can only be transported to the area close to Taoer River, which leads to the shortage of surface water in the area far from Taoer River, and only groundwater can be exploited for irrigation.

Due to the open channel, the process of transporting water resources will lose nearly 50 percent, and the farther the transport distance, the more serious the water loss is. Statistics show, When the water shortage in the month was between 0 and 20 percent, Area of major impact I; region When the water shortage was between 20% and 40% in the month, Major impact areas are region I and region II; and When the water shortage was between 40% and 80% in the month, Major impact areas are region I, region II and region III; When the water shortage was between 80% and 100% in the month, Major impact areas are region I, region II, region III and region SI. See figure 1 for details.

According to the water shortage rate of Taoer River irrigation area in Figure 2, the affected areas of each month caused by water shortage in irrigation area can be determined, as detailed in Table 2.

![Figure 3. Area Map of Water-scarce Area in Taoer River Irrigation Area.](image-url)
Table 2. Water shortage area and water shortage rate per month in Taoer River Irrigation District.

| Month   | Water scarcity areas          |
|---------|-------------------------------|
| May     | Region I, region II           |
| June    | Region I, region II, region III |
| July    | Region I                      |
| August  | Region I                      |
| September | Region I                  |

Taoer River irrigation area is two irrigation modes, the whole surface water irrigation mode and the surface water and groundwater mixed irrigation mode, in which the region IV is the whole surface water irrigation mode, the region I, region II and the region III are both surface water and groundwater mixed irrigation mode. In view of the current situation of water shortage in Taoer River Irrigation District, the economic profit and loss analysis under different irrigation modes is carried out below, which provides constructive suggestions for the development of Taoer River Irrigation District.

4.2. Analysis of Economic Profit and Loss under Different Irrigation Patterns in Irrigation Areas

According to the economic loss accounting model formula, the economic loss of region I, region II and region III can be calculated under the condition of insufficient water supply in irrigation area. Turns out, Area I loss of 39.54 million yuan, 31.7 per cent of total losses; Area II loss of 35.76 million yuan, 28.6 per cent of total losses; Area III loss of 49.56 million yuan, accounting for 39.7% of the total loss, see Figure 4 for details.

Figure 4. Area and economic losses of different affected areas.

Table 3. Water scarcity months in different regions.

| Name of name | Water shortage month          |
|--------------|------------------------------|
| Region I     | May, June, July, August, September |
| Region II    | May, June                    |
| Region III   | June                         |
In view of the difference of water shortage month, we analyze the corresponding economic profit and loss in different regions to ensure the optimal scheme to alleviate the shortage of water resources in Taoer River Irrigation District.

4.2.1. Economic Profit and Loss Analysis of Adjustment of Water Diversion Plan in Irrigation District.
Taoer River Irrigation District Administration buys water from the Charson Reservoir in the upper reaches of Taoer River, and then sells it to farmers in Taoer River Irrigation District for agricultural production irrigation, as shown in Figure 3. According to the different water demand of Taoer River Irrigation District every month, the amount of water purchased in Irrigation District is also different.

Table 3 shows that the region III is only affected by water shortage in June, so consider adjusting the water diversion plan and canceling the planned water diversion and region II in April, July, August and September, instead of III. The region water supply in June

Region III June water demand $m = 30.64$ million
Region I April and Region II Water requirements $m = 15.96$ million in April, July, August and September

Taking into account, however, that the longer the transport distance, the greater the loss of water, the amount of water originally transported to region I and region II is now transported to a closer area III, estimated at a loss rate of 50 per cent, with region I and region losses of approximately $m = 31.92$ million of the original and reduced water requirements remaining [3]. As a result, Area 3 becomes full surface water irrigation and the economic loss is 0.5% the total water demand in June.

![Figure 5. Comparison of Economic Losses before and after Water Adjustment in Regions.](image)

As can be seen from Figure 5, after the adjustment of water volume between regions, the economic loss is reduced by 26.23 million yuan. In addition, due to the need for irrigation district managers to check the amount of water and collect the cost of water after each month of water diversion in each area of irrigation district, after the adjustment of this scheme, the workload of irrigation district managers is reduced and the management cost is saved.

In summary, this adjustment scheme helps to reduce the economic loss and water loss of irrigation area, and also saves the management cost of irrigation area.

4.2.2. Economic Profit and Loss Analysis under Single Groundwater Irrigation. When the region I in April and the region II in April, July, August and September adjusted the supply area III, the irrigation
mode of region I and region II changed from surface water and groundwater mixed irrigation to groundwater single irrigation.

Figure 5 shows that for region I and region II, groundwater single irrigation compared with the original surface water and groundwater mixed irrigation loss of 23.33 million yuan. In view of this situation, this paper attempts to change this area from paddy field planting to dry field planting, and to explore its economic gains and losses.

4.2.3. Analysis of economic gains and losses from water-to-dry fields. This paper intends to change the region I and region II under single groundwater irrigation from paddy field to dry field. Soybean and corn are selected as alternative crops.

Combined with the basic data of crops in Table 1, the economic losses of region I and region II compared with rice under single groundwater irrigation can be obtained, and the corresponding water saving can also be obtained. According to the management method of collecting and using water resources fee in Jilin Province, the compensation fee for exploiting groundwater resources in Baicheng City is 120 yuan/m$^3$. The possible economic value of water conservation can be estimated, as detailed in Table 4.

From the point of view of groundwater protection, water to dry field can reduce the overexploitation of groundwater; from the point of view of water saving, water to dry field can be used for production and domestic water, which can also create economic value and make up for the economic loss of water to dry field.

Generally speaking, after the paddy field is changed to dry field, the low-lying land is easy to flood, the soil quality is relatively cold, the plate knot, the air permeability is poor, the fertility is low, therefore, without increasing the economic loss, it is suggested to plant the soybean which likes moisture and has the function of changing soil and fertilizer [11].

Table 4. Economic benefits of crops converted to drylands.

| Name of name          | Rice - Corn | Rice - Soybean |
|-----------------------|-------------|----------------|
| Economic losses/$10,000 | 13985       | 13152          |
| Water saving m $10,000^3 | 4303        | 1769           |
| Water saving value per 10,000 yuan | 516360 | 212280         |
| Total economic gain/loss/gain | 502375 | 199128         |

5. Conclusion

In this paper, the situation of water shortage in irrigation area in dry year due to the aggravation of climate change is studied. In this paper, the economic loss accounting model of irrigation area is established to analyze the dilemma of water resources allocation and the economic profit and loss of irrigation area under different irrigation modes. On the basis of the accounting results, it is suggested that the region III, should adjust the water diversion plan of irrigation area to meet the water diversion of region III, and for region I and regions with groundwater single irrigation after water transfer, the paddy field should be changed to dry field. Therefore, adjusting the water diversion plan of irrigation area and changing groundwater to dry field will be the transformation and development direction of irrigation area in semi-arid area.

6. References

[1] Li Ping, Wei Xiaomei. Effects of Climate Change on Agricultural Water Demand in Irrigation District [J]; and Journal of Water Resources and Water Engineering, 2012, 01: 81-85.

[2] Bird D N, Benabdallah S, Gouda N, et al. Modelling climate change impacts on and adaptation strategies for agriculture in Sardinia and Tunisia using AquaCrop and value-at-risk [J]. Science of The Total Environment, 2016, 543: 1019-1027.

[3] Wang Z, Zhang H, Lu X, et al. Lowering carbon footprint of winter wheat by improving
management practices in North China Plain [J]. Journal of Cleaner Production, 2016, 112: 149-157.

[4] Wu Pu, Zhao Xining. Effects of climate change on water use and food production in agriculture in China [J]; and Journal of Agricultural Engineering, 2010, 02: 1-6.

[5] Feng Lianhong. Discussion on the Way of Transformation and Development of [J]. Pumping Station Irrigation District Shanxi Water Conservancy, 2014, 04: 11-12.

[6] Research Progress of [6] Qi Xuebin, Huang Zhongdong, Qiao Dongmei, Zhang Xianchao, Li Ping [J]. On Rational Allocation of Water Resources in Mathiasn N Andersen. Irrigation District advances in water science, 2015, 02: 287-295.

[7] Zhang Zhanyu, Si Han, Feng Baoping, Hu Chao, Lu Mengxing. A Model for Optimal Allocation of Agricultural Water and Soil Resources in Water-deficit Irrigation Area [J]; and Journal of Water Resources, 2014, 04: 403-409.

[8] Han Lu, Yue Chunfang, Zhang Shengjiang, he Cheng. Allocation of Agricultural Water Resources in the Juntang Lake Basin Based on Total Quantity Control [J]; and water saving irrigation, 2015, 10: 71–73+77.

[9] The king. A Study on Ecological Compensation Mechanism of Water Replenishment to Sea Wetlands Jilin University, 2012.

[10] Yin Zhiqiang, Qin Xiaoguang, Li Changsheng. [J]. On Water Consumption and Water Deficiency of Main Crops in Three Northeast Provinces Science and Technology Bulletin 2009, 13: 42-49.

[11] Cheng Yanxi, Kong Xiangmei, more rigid. [J]. On the Technical Measures for Soybean Cultivation in the Dry Field of Water Reform in Jilin Province Jilin Agricultural Science, 2004, 06: 23-24.