Research on the countermeasures of the reduction in water transfer from the Yellow River in Yinchuan Plain, China

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Abstract

Aimed at the problem of water shortage for irrigation while reducing the water transfer from the Yellow River in Yinchuan plain, by using hydrogeological numerical model, this paper proposed a set of solutions of combining well irrigation and channel irrigation to satisfy the water demand of agriculture. The result shows that, when the reduction is less than 400 million m³/a, increasing well irrigation can meet the demand of agriculture, while the reduction is between 400 and 930 million m³/a, increasing well irrigation as well as decreasing the field irritation quota can also work. But as for the reduction is greater than 1 billion m³/a, we cannot meet the demand of agricultural irrigation, and this will have great effect on the social economy and ecological environment.

Keywords: Yinchuan Plain; reduction; water transfer from the Yellow River; well irrigation; irrigation quota

1. Introduction

Yinchuan Plain is located in the northern part of Ningxia Hui Autonomous Region, China, and the upper and middle reaches of the Yellow River. Yinchuan Plain is the most developed industrial areas of the Ningxia Hui Autonomous Region, and is also one of China's most ancient Yellow River irrigation areas in Ningxia. It has long enjoyed the good reputation of “Saishang Jiangnan” which means the southern type of scene in the northern frontier. Yinchuan Plain has benefited from the long history of gravity irrigation from Yellow River. However, Yinchuan Plain is located in the typical inland arid region and the transitional zone between desert and grassland. In this region, precipitation is scarce; evaporation is strong; environment capacity is small; and the ecological environment is very fragile [1].
Because of the shortage of water supply, Yellow River Conservancy Commission has reduced the volume transferred from Qingtong Gorge to Yinchuan Plain. Under such circumstance, how should we cope with the changes to meet the demand of agricultural irrigation of Yinchuan Plain? What’s the response of the groundwater of Yinchuan Plain? These issues are concerned by the local government and the relevant management department.

We use the numerical model of groundwater flow developed previously [2] to design the calculation scenarios respectively to analyze and research the problems under the reduction of the water transfer from Yellow River in normal years.

2. The research on reduction of the water transfer from the Yellow River

2.1. The design of calculation scenarios

At present Yinchuan Plain is irritated mainly by water transfer from the Yellow River, under the condition of unchanged agricultural area, if the water transfer from Yellow River was reduced, we would solve the problem caused by the shortage of water supply by saving water and/or pumping more groundwater. Therefore, when designing the scenarios, we should consider the way of irrigation by saving water, reducing the irritation quota (IQ), as well as the combination of well irrigation and canal irrigation to deal with the problem of the reduction of water transfer from Yellow River. For the decrease proportion of field irritation quota, we have considered 6 situations, that is respectively 0%, 5%, 10%, 15%, 20% and 25%( the proportion just represents one kind of possibility in future and does not mean reduction will be taken according to this number); under the condition of different field irrigation quota, according to the proportion of the volume of well irrigation(W) accounting for the total volume of irrigation(T), we have considered the proportion of well irritation with 0%, 5%, 10%, 15%, 20%and 25% respectively, so there are 36 scenarios in combination by this way (Tab. 1).

| Ratio of W/T | decrease proportion of field irritation quota |
|-------------|-----------------------------------------------|
|             | 0     | 5%   | 10%  | 15%  | 20%  | 25%  |
| 0           | S1    | S2    | S3    | S4    | S5    | S6    |
| 5%          | S7    | S8    | S9    | S10   | S11   | S12   |
| 10%         | S13   | S14   | S15   | S16   | S17   | S18   |
| 15%         | S19   | S20   | S21   | S22   | S23   | S24   |
| 20%         | S25   | S26   | S27   | S28   | S29   | S30   |
| 25%         | S31   | S32   | S33   | S34   | S35   | S36   |

These 36 scenarios were simulated respectively by use of the numerical model, which was developed previously by using the numerical simulation software Modflow [3] developed by the United States Geological Survey, under the average hydrological, meteorological conditions and the current industrial and domestic exploitation volume conditions. And the statistic was made for the reduction of water transfer from the Yellow River and evapotranspiration from groundwater, as well as the areas of the sections with groundwater drawdown of 0-0.5m, 0.5-1.0m, 1.0-2.0m, 2.0-3.0m, >3.0m of each scenario compared with the current situation.
2.2. Comprehensive analysis of the calculation results

Fig. 1 takes scenario 22, in which the ratio of well irrigation is 15% and the reduction of water transfer is 15%, as an example, it drew up the changing curve of the area with different drawdown sections of 0-0.5m 0.5-1m, and greater than 0.5m along with the changes of time, according to the analysis we can get the following rule (other scheme is similar to this one, unnecessary to go into details here):

During the irrigation period (May-September and November), area with drawdown of 0-0.5m under each scenario gradually decreased during May and September, in November there is a slight increase; area with drawdown over 0.5m gradually increased during May and September, in November there is a slight decrease. That is mainly because of the reduction of irrigation quota and increase of well irrigation during May and September. The reduction of irrigation quota makes the recharge from irrigation water infiltration decreases, and the increase of well irrigation means the enlargement of groundwater discharge, which both leads to the decrease of ground water table, thus the area with drawdown less than 0.5m gradually decreased and the area with drawdown more than 0.5m gradually increased. At the same time since October is not irrigation period, the ground water table rose to certain extent which makes the changes of the water table in November differ from other month.

When we save irrigation water by reducing the irrigation quota, it will reduce the water volume infiltrating into the groundwater with a small amount because only a small part of irrigation water can infiltrate into groundwater. But when we get more water for irrigation by pumping groundwater, it will extract water from aquifer directly with a relative great amount. So the way of increasing the ratio of well irrigation will put greater impact on the groundwater system than the way of reducing the irrigation quota. That means the groundwater level declines more along with the increase of well irrigation ratio under the same irrigation quota, and the groundwater drawdown changes little while the irrigation quota changes under the same ratio of well irrigation.

2.3. Optimized scenario of the different reduction in Yellow River irrigation

By grouping the scenario according to the reduction of water transfer from the Yellow River, we optimized each group and selected the best one to help relevant department make the suitable policy according to different reduction in irrigation. Scenario with different reduction can be grouped into 9 groups (Tab. 2).

![Figure 1 The changing curves of the area with drawdown of 0-0.5m, 0.5-1m and >1m compared with current situation of each month under the selected scenario](image-url)
Table 2 List of the area of sections with different drawdown of water table and reduction in evapotranspiration of each scenario

| Group | Scenario | Area of different drawdown section (km²) | Decrease of ET (10^3 m³/a) |
|-------|----------|------------------------------------------|---------------------------|
|       |          | 0-0.5m | 0.5-1.0m | 1.0-2.0m | 2.0-3.0m | >3.0m |
| 1     | 2        | 6698.25 | 0         | 0        | 0        | 0     | 0.16 |
|       | 7        | 6533.96 | 164.13    | 0.17     | 0        | 0     | 0.76 |
| 2     | 3        | 6698.25 | 0         | 0        | 0        | 0     | 0.32 |
|       | 8        | 6486.50 | 210.96    | 0.79     | 0        | 0     | 0.88 |
|       | 13       | 6032.00 | 490.71    | 175.54   | 0        | 0     | 1.51 |
| 3     | 4        | 6697.38 | 0.87      | 0        | 0        | 0     | 0.48 |
|       | 9        | 6426.46 | 248.88    | 22.91    | 0        | 0     | 1    |
|       | 14       | 5955.04 | 551.29    | 191.92   | 0        | 0     | 1.59 |
|       | 19       | 5045.79 | 1211.79   | 337.25   | 103.42   | 0     | 2.24 |
| 4     | 5        | 6606.25 | 92        | 0        | 0        | 0     | 0.64 |
|       | 10       | 6363.42 | 293.83    | 68       | 0        | 0     | 1.12 |
|       | 15       | 5876.79 | 605.54    | 215.92   | 0        | 0     | 1.67 |
|       | 20       | 4967.67 | 1263.58   | 360.63   | 106.37   | 0     | 2.28 |
|       | 25       | 3717.96 | 2150.33   | 604.29   | 149.75   | 75.92 | 2.94 |
| 5     | 6        | 6521.75 | 176.5     | 0        | 0        | 0     | 0.8  |
|       | 11       | 6232.21 | 363.42    | 102.62   | 0        | 0     | 1.24 |
|       | 16       | 5782.54 | 672.42    | 243.29   | 0        | 0     | 1.75 |
|       | 21       | 4886.29 | 1318.29   | 380.88   | 112.79   | 0     | 2.32 |
|       | 26       | 3709.88 | 2157.58   | 603.67   | 152.29   | 74.83 | 2.95 |
|       | 31       | 2648.88 | 2669.04   | 964.38   | 228.00   | 187.95| 3.62 |
| 6     | 12       | 6141.96 | 427.88    | 128.41   | 0        | 0     | 1.36 |
|       | 17       | 5674.29 | 750.58    | 273.38   | 0        | 0     | 1.83 |
|       | 22       | 4803.29 | 1379.88   | 398.38   | 116.7    | 0     | 2.37 |
|       | 27       | 3704.83 | 2162.71   | 601.71   | 155.04   | 73.96 | 2.96 |
|       | 32       | 2683.75 | 2665.08   | 941.33   | 225.88   | 182.21| 3.6  |
| 7     | 18       | 5561.67 | 829.75    | 306.83   | 0        | 0     | 1.91 |
|       | 23       | 4713.46 | 1449.58   | 413.71   | 121.5    | 0     | 2.41 |
|       | 28       | 3699.79 | 2167.04   | 601.33   | 157.75   | 72.34 | 2.96 |
|       | 33       | 2722.25 | 2655.25   | 921.67   | 222.63   | 176.45| 3.57 |
| 8     | 24       | 4630.21 | 1512.38   | 428.38   | 127.28   | 0     | 2.45 |
|       | 29       | 3697.79 | 2169.92   | 598.83   | 161.38   | 70.33 | 2.97 |
|       | 34       | 2766.25 | 2637.63   | 906.08   | 219.88   | 168.41| 3.54 |
| 9     | 30       | 3698.42 | 2168.58   | 598.00   | 164.58   | 68.67 | 2.98 |
|       | 35       | 2810.42 | 2620.29   | 889.71   | 216.04   | 161.79| 3.52 |
|       | 36       | 2863.04 | 2593.46   | 871.67   | 215.33   | 154.75| 3.49 |

Among the nine groups in Tab. 2, in accordance with each scenario’s result of numerical simulation of groundwater flow, we can choose out relatively reasonable scenarios. In the selection process, we mainly
considered the change in the area of sections with different drawdown and the reduction in evapotranspiration. For the drawdown of groundwater table, as the area with drawdown of 2-3 m is too large or when the drawdown is larger than 3 m, it will cause great negative impact on crops, vegetation and other ecological environment, therefore, if the scope with the above situation under one scenario is larger than that under another scenario, the former scenario is unreasonable; For reduction in the evapotranspiration, if the reduction of one scenario is larger than that of another scenario, the water use efficiency of the former is higher with reduction in invalid evapotranspiration losses, therefore, it is the relatively reasonable scenario. Because the above factors have interactive and mutual influence, therefore, when selecting the optimal scenario, they were comprehensively considered, as follow by taking 2 typical groups as examples.

There are scenario 4, 9, 14 and 19 in the first typical group which is group 3, and the reduction of water transfer from Yellow River of these scenarios amounts to 371-384 million m$^3$/a, compared with the result of the calculation (Tab. 2). Through comparison of calculation results of these scenarios, it can be seen that the scenario with area of water table drawdown of 0-0.5 m from large to small are scenario 4, 9, 14, 19, while the scenario with area of water table drawdown of 0.5-1.0 m,1.0-2.0 m from large to small are 19, 14, 9, 4 and only scenario 19 has the area with water table drawdown of 2-3m, which is 103.42km$^2$, while it is 0 in other scenarios; Reduction in evapotranspiration compared with the current situation in the scenario from large to small is scenario 19, 14, 9, 4, which is respectively 224, 159, 100, 48 million m$^3$/a. Though in scenario 19, there is area with 2-3m drawdown, its area just accounts for 1.5% of the total Yinchuan Plain, at the same time, scenario 19 has the smallest area with drawdown of 0-0.5m, and the largest area with drawdown of 0.5-1.0m, 1.0-2.0m and the largest induction volume in evapotranspiration compared with the current situation. Combined with the analysis of above factors, scenario 19 is more reasonable.

Because the reduction of water transfer from the Yellow River is small, group 1 and group 2 have the similar results to the first typical group. The way of increasing the amount of groundwater exploitation for irrigation can meet the water demand of agriculture. In these groups, scenario 7 and 13 are the reasonable scenarios.

There are scenario 6,11,16,21,26 and 31 in the second typical group which is group 5, and the reduction of water transfer from Yellow River of these scenarios amounts to 601-639 million m$^3$/a, compared with the result of the calculation(Tab. 2) we can conclude that the areas with drawdown between 0-0.5 m under these scenarios from large to small is respectively scenario 6, 11, 16, 21, 26 and 31; areas with drawdown of 0.5-1.0m and 1.0-2.0m under these scenarios from large to small is respectively scenario 31, 26, 21, 16, 11 and 6, the scenarios with drawdown of 2-3m are scenario 21, 26 and 31, the area of these sections is 112.79, 152.29 and 228.00 km$^2$ respectively, the scenarios with drawdown over 3m are scenario 26 and 31, with the area of 74.83 and 187.95 km$^2$ respectively. For each scenario compared with the current situation, the reduction in evapotranspiration under these scenarios from great to small is in turn scenario 31, 26, 21, 16, 11 and 6 with corresponding volume of 362, 295, 232, 175, 124 and 80 million m$^3$/a. Since scenario 26 and 31 have some regions with the drawdown over 3m, which brings about negative effect on crop and vegetation, so scenario 26 and 31 are unreasonable. Although scenario 21 has some regions with the drawdown of 2-3m, its area only accounts for 1.68% of the whole areas of Yinchuan Plain, at the same time, in this scenario the area with drawdown of 0-0.5m is smaller than that in any other scenario, while the area with drawdown of 0.5-1.0m, 1.0-2.0m is larger than that in any other scenario, the reduction in evaporation volume is larger than in any other scenario, therefore scenario 21 is much more reasonable.

Because the reduction of water transfer from the Yellow River is relative great, group 4, 6, 7, 8 and 9 have the similar results to the second typical group. The way of increasing the amount of groundwater
exploitation for irrigation as well as decreasing the field irrigation quota can meet the water demand of agriculture. In these groups, scenario 20, 22, 23, and 24 are the reasonable scenarios.

By the same method, we can choose the entire optimized scenario for each group. These results are listed in Tab. 3. It was worth to point out that each scenario in the last group has some regions with drawdown over 3m with the area of 68.67, 161.79 and 154.75 km². It has caused negative effect on crop and vegetarian and other ecological environment, so there is no reasonable scenario in this group.

From the optimized results we can conclude that when the reduction of water transfer from Yellow River is less than 400 million m³/a, the demand of agricultural irrigation in Yinchuan plain can be satisfied by the way of combination of well irrigation and canal irrigation instead of decreasing irrigation quota; when the reduction of water transfer from Yellow River is between 400-930 million m³/a, the demand of agricultural irrigation can be satisfied through both the combination of well irrigation and canal irrigation and a certain reduction to proper proportion of irrigation quota; when the reduction of water transfer from Yellow River is more than 1 billion m³/a, there is no suitable ratio of well irrigation and no suitable proportion for cutting irrigation quota to meet the demand of the agricultural irrigation in Yinchuan plain, and accordingly it will bring about great effect on the social economy of the plain and the ecological environment.

3. Conclusions

As for different decrease degree of water transfer from Yellow River, different optimized scenarios have been carried out by using the method of controlled numerical experiment. When the decrease of water transfer from the Yellow River is less than 400 million m³/a, we can meet the demand of agricultural irrigation by increasing the amount of groundwater exploitation for irrigation. While the decrease of water transfer from the Yellow River is between 400 million m³/a and 930 million m³/a, we can meet the demand of agricultural irrigation by increasing the amount of groundwater exploitation for irrigation as well as by decreasing the field irrigation quota. As for the decrease of water transfer from the Yellow River is greater than 1 billion m³/a, we cannot meet the demand of agricultural irrigation, and this will have great effect on the social economy and ecological environment.

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