Analysis of Groundwater Balance in Well Irrigation Over Exploitation Area of Liaocheng City

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Abstract. In order to study the influence of water level dynamic factors in the over-extraction area of well irrigation, hydrogeological surveys were carried out in the over-extraction area and outside the well-poor area, and data were collected to make equal water level maps for different years from 2011 to 2015. The well water level map was determined according to the water level map. The scope of groundwater balance analysis in the mining area analyzes the groundwater balance in the area of 85.23km², 79.3km² and 62.15km² of the groundwater over-exploitation area in Guanxian, Shenxian and Linqing, respectively, and calculates the groundwater recharge and excretion in each district from 2011 to 2015 year. As well as the shallow groundwater storage variables, it is concluded that the groundwater balance in the Liaocheng Guanxian, Shenxian and Linqing well irrigation over-exploitation areas in 2011~2015 years is negatively balanced.

1. Introduction
In recent years, dry weather is frequent in China, and the water resources in Liaocheng City are extremely scarce, coupled with the low efficiency of water use, which has seriously hindered the development of the local agricultural economy [1]. For a long time, groundwater has been one of the main sources of industry, agriculture and life in Liaocheng City [2]. Agricultural irrigation water is the most important part of the total water consumption of the national economy, and is an important basis for the rational development and utilization of water resources [3]. Groundwater is an important part of water resources. Water shortage and uneven distribution of time and space. With the contradiction between water supply and demand in irrigation districts, it has become an important issue hindering China's economic and social development.

Therefore, it is of great significance to analyze the groundwater recharge and excretion of the groundwater in the well-extracted mining area. Through the balance analysis of supply and demand water, the quantitative relationship of various factors in the groundwater circulation system is obtained, which provides a theoretical reference for the future regulation of water resources in irrigation districts.

2. Study Area
The Liaocheng research area is located in the Yellow river flood plain area and belongs to the warm temperate semi-arid monsoon climate zone. The average rainfall (568~93mm) for many years (2011~2015) is obvious. The spatial and temporal distribution of precipitation in the study area is extremely uneven. The monthly precipitation in the year is about 72.3 or more concentrated in the flood
season (June to September). The interannual variation often shows the phenomenon of continuous and continuous dryness, with obvious periodicity.

In the Liaocheng Guanxian research area, 199# and 200# of Qingshui town were selected, and 174# of Beitaotao town was selected outside the area. Similarly, 21B# and 161# of Zhaocheng town were selected in research Area of Liaocheng Shenxian, and 139# outside the area was located at Shibalipu town. selected 181# and 182# of Xinhua Office in research area of Liaocheng Linqin and 145A# of Bacha town outside the area as the research object. According to the collected observation data of groundwater level in the study area and surrounding areas from 2011 to 2015, the groundwater level maps are drawn (Fig.1), and the areas of Guanxian, Shenxian and Linqin research areas are determined to be 85.23km$^2$, 79.3km$^2$ and 62.15km$^2$.

3. Groundwater balance analysis

3.1. Changes in groundwater storage

The shallow groundwater storage variable refers to the difference between the shallow groundwater storage at the beginning of the calculation period and at the end of the calculation period, which is usually calculated by the following formula:

$$\Delta W = 10^4 \cdot (H_1 - H_2) \cdot \mu \cdot F \quad (1)$$

As the formula, $\Delta W$—Change in groundwater consumption ($10^4 \text{ m}^3$); $H_1$—the groundwater level at the beginning of the period (m); $H_2$—the groundwater level at the end of the period (m); $\mu$—specific yield of Research area; $F$—Irrigation area(km$^2$).

The representative observation wells were selected to study the groundwater balance in the study area, so the Guanxian, Shenxian and Linqin study areas were selected 200#, 21B# and 181#. The water supply “$\mu$” of Guan xianxian and Shen xianxian is 0.24, and the Linqin Research Area is 0.17. The
annual Change in groundwater consumption during the period from 2011 to 2015 are calculated (Table 1).

| Research area | \(H_1(\text{m})\) | \(H_2(\text{m})\) | \(F(\text{m})\) | \(\Delta W(10^4 \text{m}^3)\) |
|---------------|-----------------|-----------------|---------------|------------------|
| Guan xian     | 23.8            | 22.88           | 85.23         | 1881.88          |
| Shen xian     | 28.63           | 26.83           | 79.3          | 3425.76          |
| Linqing       | 25.84           | 24.31           | 62.15         | 1616.52          |

3.2. Recharge rate of research area

3.2.1. Precipitation recharge. The calculation formula of precipitation recharge is:

\[ Q_1 = \sum_{i=1}^{n} 0.1 \cdot \alpha_i \cdot P_i \cdot F \quad (i=1,2,3,4,5) \] (2)

As the formula, \(Q_1\)—Rainfall infiltration recharge \((10^4 \text{ m}^3)\); \(P_i\)—Precipitation for the \(i\)-th year(mm); \(\alpha_i\)—Rain infiltration replenishment factor for the \(i\)-th year.

The precipitation data of the well irrigation over-exploitation area from 2011 to 2015 was calculated. The precipitation infiltration coefficient of the study area was determined to be 0.17~0.2, and the annual precipitation recharge amount in the research area of the well irrigation over-exploitation area was calculated (Table 2).

| Research area | Total precipitation (mm) | Rainfall recharge \((10^4 \text{ m}^3)\) | |
|---------------|--------------------------|------------------------------------------|
| Guan xian     | 2489.2                   | 2969.12                                  |
| Shen xian     | 2473.5                   | 3318.18                                  |
| Linqing       | 2885.6                   | 3146.58                                  |

3.2.2. Lateral inflow. Calculated Lateral inflow \((Q_2)\) quantity using the Darcy formula:

\[ Q_2 = 10^2 \cdot K \cdot I \cdot F \cdot T \] (3)

As the formula, \(Q_2\)—lateral inflow \((10^4 \text{ m}^3)\); \(K\)—Permeability coefficient(m/d); \(I\)—hydraulic gradient; \(T\)—time(a).

Take the 174#, 139# and 145A# outside the Guanxian, Shenxian and Linqing research areas to the distances of 200#, 21B# and 181# in the well-extracting mining area and the average water level in 2011~2015, and calculate Lateral inflows from different years (Table 3).

| Research area | \(h_1\) | \(h_2\) | \(\Delta h\) | Distance(m) | \(I\) | \(Q_2(10^4 \text{ m}^3)\) |
|---------------|--------|--------|-------------|-------------|------|------------------|
| Guan xian     | 29.25  | 24.03  | 5.22        | 7100        | 0.000735 | 305.19          |
| Shen xian     | 32.65  | 28.08  | 4.57        | 15700       | 0.000291 | 112.36          |
| Linqing       | 25.62  | 25.50  | 0.12        | 23600       | 0.000005 | 1.54            |
3.2.3. The return amount of irrigation. The return amount of irrigation refers to the supply of groundwater through the aeration zone after the irrigation water enters the farmland. The calculation formula is:

$$Q_3 = \sum_{i}^{n} \beta_i \cdot F \cdot q/10^2 \quad (i=1,2,3,4,5)$$  \hspace{1cm} (4)

As the formula, $Q_3$—The return amount of well irrigation ($10^4$ m$^3$); $\beta_i$—Irrigation infiltration coefficient for the i-th year; $q$—Annual irrigation quota (m$^3$/acre).

According to the survey $\beta_i$ is 0.084, so the annual return of well irrigation in the well irrigation over-exploitation area from 2011 to 2015 is calculated (Table 4).

| Research area | Annual irrigation quota (m$^3$/acre) | $Q_3$ ($10^4$ m$^3$) |
|---------------|------------------------------------|---------------------|
| Guan xian     | 7016.49                            | 502.56              |
| Shen xian     | 10389.81                           | 692.40              |
| Linqing       | 8380.81                            | 437.73              |

3.3. Excretion amount of Study area

According to the following formula:

$$Q_{out} = \sum_{i}^{n} F \cdot q/10^2 \quad (i=1,2,3,4,5)$$  \hspace{1cm} (5)

The amount of irrigation in the LiaoCheng Research Area from 2011 to 2015 was collected as shown in the table 5.

| Research area | Annual irrigation quota (m$^3$/acre) | $Q_{out}$ ($10^4$ m$^3$) |
|---------------|-------------------------------------|-------------------------|
| Guan xian     | 7016.49                             | 5982.85                 |
| Shen xian     | 10389.81                            | 8242.82                 |
| Linqing       | 8380.81                             | 5211.02                 |
3.4. Analysis of Groundwater Balance

The water balance relationship of Liaocheng Research Area can be generalized as Figure 2:

![Groundwater Balance Diagram](image)

**Figure 2.** The picture of groundwater balance relationship in Liaocheng study area.

According to the following formula:

\[ X = Q_{in} - Q_{out} + \Delta W = Q_1 + Q_2 + Q_3 - Q_{out} + \Delta W \] (6)

\[ \delta = \frac{X}{Q_{in}} \times 100\% \] (7)

As the formula, \( X \) — Absolute balance difference \((10^4 \text{ m}^3)\); \( \delta \) — Relative balance difference.

The groundwater balance factors calculated in the previous calculations are substituted into the groundwater balance model of the irrigation area. The calculation results of the groundwater balance analysis are listed in Table 6. The composition of the specific recharge of groundwater in the irrigation area can be seen in from Figure 3 to Figure 5.

**Table 6.** Table of groundwater balance relations in research area from 2011 to 2015.

| Research area | \( \Delta W(10^4 \text{ m}^3) \) | \( Q_{in}(10^4 \text{ m}^3) \) | \( Q_{out}(10^4 \text{ m}^3) \) | \( X(10^4 \text{ m}^3) \) | \( \delta(\%) \) |
|---------------|-------------------------------|-------------------------------|-------------------------------|----------------|------------|
| Guanxian      | 1881.88                       | 502.56                        | 2969.12                      | -2205.98       | -324.10    | -8.58       |
| Shenxian      | 3425.76                       | 692.40                        | 3318.18                      | -4119.88       | -694.12    | -16.84      |
| Linqin        | 1616.52                       | 437.73                        | 3146.58                      | -1625.17       | -8.65      | -0.24       |
4. Conclusion

(1) In the five years from 2011 to 2015, the total excretion in Guanxian, Shenxian and Linqing research areas were larger than the total recharge in the study area, and they were all in a negative equilibrium state. The relative equilibrium difference was less than 20%, and the negative equilibrium state of the study area was Shenxian > Guanxian > Linqing.

(2) The total amount of shallow groundwater stored in Liaocheng Research Area is 69,264,600 m$^3$, the total replenishment is 11,485,600 m$^3$, the total exploitation is 19,436,900 m$^3$, the negative equilibrium is 7,951,300 m$^3$, and the relative equilibrium difference is 8.94%. To a certain extent, the development and utilization of groundwater in the over-exploitation area of Liaocheng well irrigation has reached a very high level, and some areas have been over-exploited or even over-exploited.

(3) Precipitation replenishment accounts for 70%~90% of the total recharge in the study area in the past five years, and artificial exploitation accounts for more than 90% of the total groundwater discharge in the study area. It can be seen that rainfall infiltration recharge and groundwater extraction are the main Groundwater balance factors.
References

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