*Desalination and Water Treatment*
www.deswater.com
doi: 10.5004/dwt.2018.22334

112 (2018) 325–333
April

# Driving factors of the evolution of groundwater level in People's Victory Canal Irrigation District, China

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Received 7 November 2017; Accepted 4 February 2018

**ABSTRACT**

It is an efficient way of dynamic characteristics and driving factors analyses of groundwater system to make clear of groundwater cycle and its influence degree by anthropogenic activities. First of all, the temporal and spatial variation law of groundwater level was analyzed based on the measured data of groundwater level in People's Victory Canal Irrigation District in 1993–2013; then, the influence degree of each influencing factor on the groundwater level was quantified by using correlation analysis; finally, the dominant driving factors influencing the evolution of groundwater level were determined using grey relational analysis. The results show that the groundwater level decreased with the decrease of precipitation, and decreased with the decrease of irrigation water from the Canal, and decreased with the increase of groundwater exploitation. Human activities played a dominant role in the variation of groundwater, and the irrigation water of wells as well as the mining of groundwater for living and industrial use was the dominant driving factors of the variation of groundwater level in the study area.

*Keywords:* Groundwater level evolution; Driving factors; People's Victory Canal Irrigation District; Human activities; Groundwater mining

## 1. Introduction

As the natural intervention by human activities increases significantly, the groundwater circulation system becomes increasingly complex, and the variation of groundwater level presents new characteristics, so how to recognize the law of groundwater circulation and its driving factors under changing conditions is one of the hot and difficult problems in hydrogeology research [1–3]. The driving force for the evolution of groundwater system is nothing more than climate change and human activities [4–6]. Relliy [7] pointed out in an area where water resource is transformed independently, the phreatic water evaporation and irrigation return recharge are controlled by artificially adjusted groundwater level [7]. Kirshen [8] analyzed the influence of global warming on the groundwater in Eastern Marseille. Scibek [9] built a 3D model with Visual Modflow as the platform, confirming that the response of groundwater level to climate change in humid areas of North American Plain is less than that to river hydrograph change. Jykama and Sykes [10] proposed to study the temporal and spatial variation of groundwater recharge by climate change using a physical process–based approach taking American Large River Basin as the study area, revealing that the temporal and spatial variation characteristics of groundwater recharge result from climate change. Scanlon et al. [11] studied the effects of agricultural ecosystems in high plains of central Texas, USA, on groundwater storage and groundwater quality, and analyzed the positive response of groundwater system to human activities. Ma et al. [12] pointed out that some artificial water conservancy projects prompt the redistribution of surface water resources, resulting in a change in spatial recharge of groundwater in southern

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Tarim Basin. Zhang et al. [13] pointed out that the expansion of irrigation area in Minqin Basin, the increase of lining canal ratio and the increase of groundwater mining quantity cause a change in groundwater recharge condition, in other words, human activity factor becomes the dominant driving factor of change in groundwater level in this area. Zhang et al. [14] pointed out that the change of precipitation is an important factor affecting the anomaly of groundwater flow field. It is thus evident that the impact of climate change on groundwater is mainly achieved by directly affecting groundwater recharge and indirectly affecting water cycle. The exploitation and utilization of water and soil resources is the main way that human activities affect groundwater, because of its disturbance to groundwater is becoming more and more obvious, it dominates the evolution of groundwater.

People's Victory Canal Irrigation District, located in the north of Henan Province in China, is the first large-scale gravity irrigation district built in the lower reaches of the Yellow River after the founding of the People's Republic of China, and is an important grain, cotton and oil production area in China. Located in the upper section of the lower reaches of the Yellow River, it has good water diversion condition, and has been developed for more than 60 years, from an initial agricultural gravity irrigation area to a multi-functional area for living and industrial water use as well as rural and urban industrial water use. With the increasing contradiction between the supply and demand of water resources in the Yellow River valley, the quantity of water diverted from the Yellow River for People's Victory Canal Irrigation District has been limited, so groundwater becomes an important source of irrigation water. Therefore, a series of problems has been brought about by the change of groundwater system in the irrigation district. For example, because of the excessive exploitation of groundwater and the decrease of irrigation water quantity from the Yellow River, the groundwater level has dropped greatly, and a groundwater depression cone has even come into being in the south of the irrigation district.

Therefore, this paper tries to analyze the temporal and spatial evolution characteristics of groundwater level in the irrigation district, and to understand the evolution law of groundwater system and analyze the driving factors and driving mechanism of groundwater level change. The results can provide scientific basis for the rational and sustainable utilization of groundwater resources and protection of ecological environment.

## 2. Materials and methods

### *2.1. Method of the evolution characteristics of groundwater level*

People's Victory Canal Irrigation District, situated 113°31′–114°25′ of east longitude and 35°0′–35°30′ of northern latitude, stretches across seven counties and one city: Xinxiang County, Hua County, Weihui County, Yuanyang County, Huojia County, Yanjin County, Wuzhi County and Xinxiang City, and covers an area of 1,486.84 km$^2$. There are 58 groundwater level observation wells, which are shown in Fig. 1 [15]. The temporal and spatial evolution characteristics of groundwater in the irrigation district were analyzed according to the average annual and average monthly data of groundwater level in 1993–2013.

According to the groundwater level of the observation wells in Fig. 1, raster maps of groundwater level in different years were generated by the Kriging Interpolation Method using ArcGIS10.0 software. Using these maps, the temporal and spatial variation characteristics of groundwater level in the irrigation district were analyzed.

### *2.2. Method of the driving factors of the groundwater evolution*

Since the change of groundwater level is influenced by many factors, in this paper the driving factors of the evolution of groundwater system were studied from the two aspects of climate change (mainly including precipitation) and human activities (including irrigation water quantity of the canal, irrigation groundwater quantity, domestic and industrial groundwater consumption, and planting area of main cultivated crops). First of all, the corresponding relationship between the groundwater depth and its influencing factors and anomaly percentage change in 1993–2013 was analyzed; then, the influence degree of each influencing factor on the groundwater level was quantified by using correlation analysis; finally, the dominant driving factors influencing the evolution of groundwater level were determined using grey relational analysis.

#### *2.2.1. Anomaly percentage*

Anomaly percentage reflected the deviation extent of an observed value in a given period:

$$p_i = \frac{x_i - x}{\bar{x}} \times 100\% \tag{1}$$

$$\bar{x} = \frac{1}{n}\sum\nolimits_{i=1}^{n} x_i \tag{2}$$

where $x_i$ was the sequence value, and $\bar{x}$ was the mean of sequence value.

#### *2.2.2. Grey relational analysis*

Grey relational analysis, an effective way to deal with uncertain variables, is a method of measuring the correlation degree between factors by analyzing the similarity or dissimilarity between factors. It does not require too much of the sample size and requires only data series that can reflect the characteristics of the system. The calculation of correlation degree is essentially a comparison of geometric shapes between curves, and the measure of correlation degree is the magnitude of the difference [16–18].

Suppose there are $m$ comparison data array ($Z_1, Z_2, \ldots, Z_m$) having certain correlation with reference data array ($Z_0$), at the same time, they have at least $N$ contemporaneous dynamic observation values, namely:

Reference data array:

$$\{Z_k(i)\}, \quad i = 1, 2, \ldots \ldots, N \tag{3}$$

Comparison data array:

$$\{Z_k(i)\}, \quad k = 1, 2, \ldots \ldots, m, \quad i = 1, 2, \ldots \ldots, N \tag{4}$$

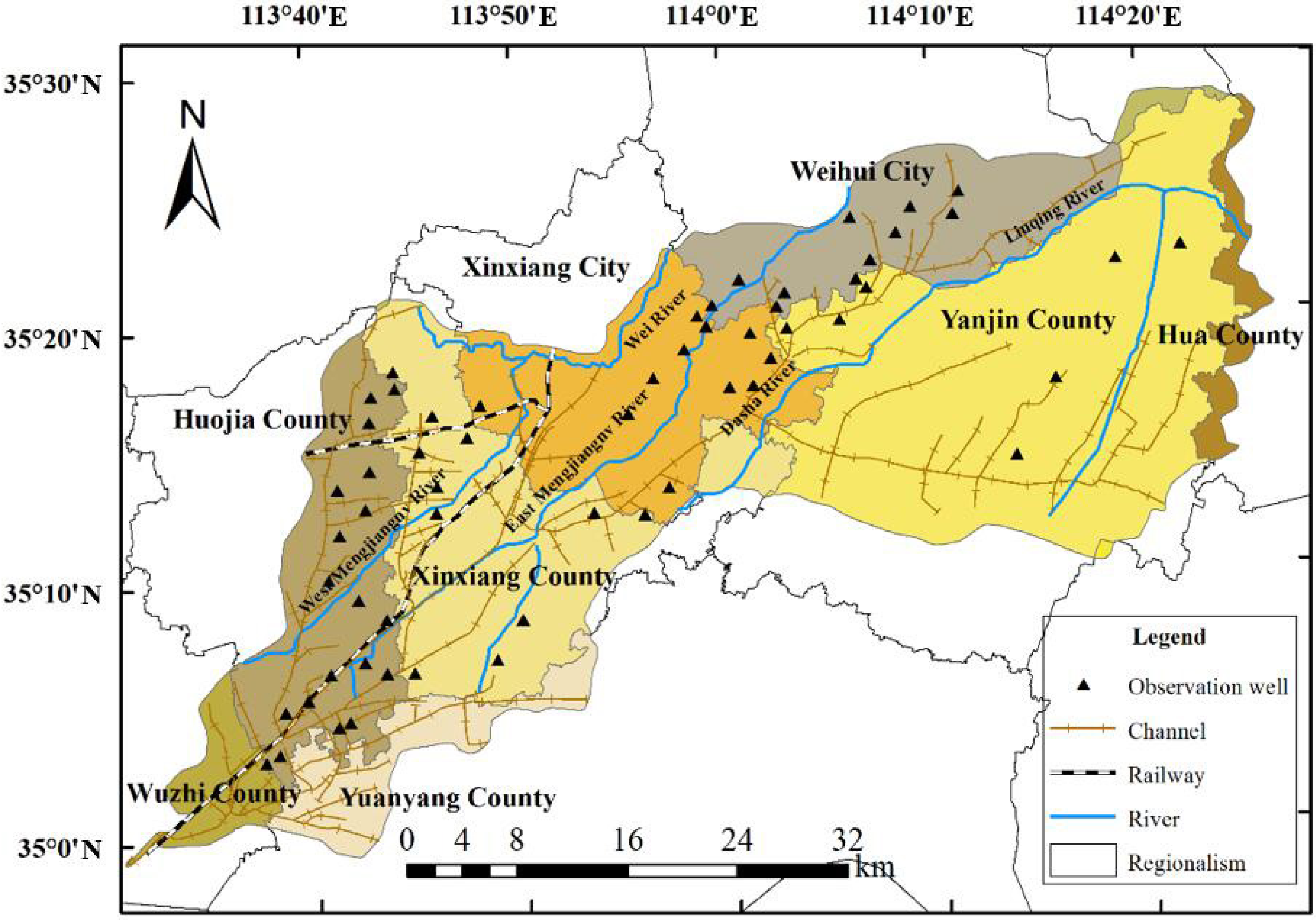


Fig. 1. Distribution of observation wells.

For ease of calculation of the correlation degree, dimensionless treatment and normalization were performed for the reference data array and comparison data array.

Reference data array:

$$Z_0 = Z_0(i) / \frac{1}{N}\sum_{i=1}^{N} Z_0(i) \quad (5)$$

Comparison data array:

$$Z_k = Z_k(i) / \frac{1}{N}\sum_{i=1}^{N} Z_k(i) \quad (6)$$

Correlation coefficient:

$$\xi_{0k}(i) = \frac{\min_{k}\min_{i}\left|Z_0(i) - Z_k(i)\right| + \varsigma \max_{k}\max_{i}\left|Z_0(i) - Z_k(i)\right|}{\left|Z_0(i) - Z_k(i)\right| + \varsigma \max_{k}\max_{i}\left|Z_0(i) - Z_k(i)\right|} \quad (7)$$

$\varsigma$ is the discrimination coefficient, it was selected between 0 and 1, and its size should not affect the order of correlation coefficients at each moment, so it generally adopted 0.5. The correlation degree was the mean of correlation coefficients at each moment, namely:

$$r_{ok} = \frac{1}{N}\sum_{i=1}^{N} \xi_{ok}(i) \quad (8)$$

## 3. Results and discussion

### *3.1. Characteristics of the evolution of groundwater level*

The groundwater flow fields in the irrigation district in 1995, 2000, 2005 and 2010 are shown in Fig. 2. The groundwater level is high in the west and low in the east in the irrigation district, specifically, the highest groundwater level was located in the Yellow River diversion area of the southwest Yellow River Beach, and the lowest groundwater level was located in the north of the irrigation district. Compared with 1995 and 2000, the area of low groundwater level in the north of the irrigation district in 2005 and 2010 showed an expansion trend.

In 1995, the groundwater level in the most parts of the irrigation district was about 70 m. The high groundwater level areas were mostly distributed in the southwest of the irrigation district, with the highest groundwater level of 80.9 m; the low groundwater level areas were mostly distributed in the northeast of the irrigation district, with the lowest groundwater level of 58.4 m [19]. The southwest and northern part of the irrigation district have the high hydraulic gradient, such as Dongzhuang Village and Chengyu Village

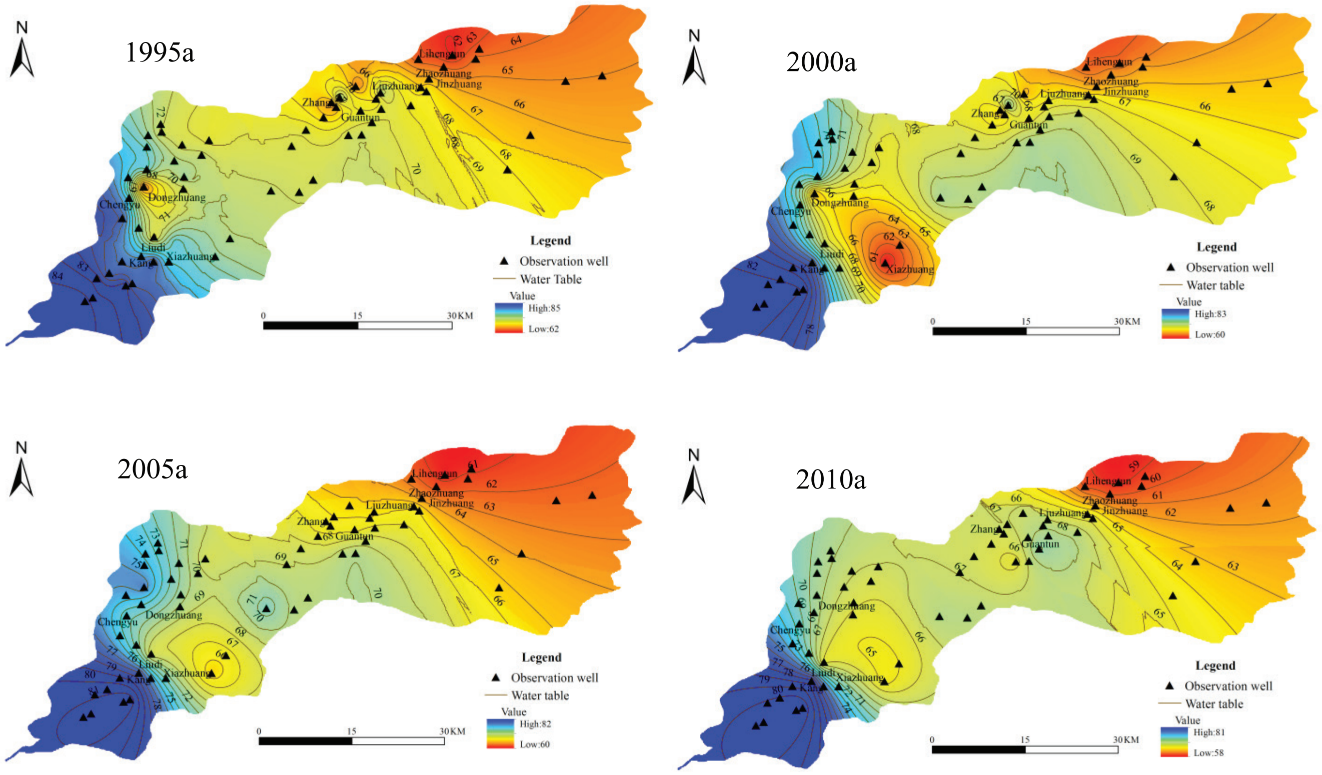


Fig. 2. Groundwater flow fields of the irrigation district.

in the west and Zhang Village and Jinzhuang Village in the north. The area formed a groundwater depression cone with an area of 33 km² and a boundary of 70 m, and its center is near Dongzhuang Village.

In 2000, the groundwater level in the most parts of the irrigation district was about 68 m. The high groundwater level areas were mostly distributed in the southwest of the irrigation district, with the highest groundwater level of 82.6 m; the low groundwater level areas were mostly distributed in the northeast of the irrigation district, with the lowest groundwater level of 60.1 m [20]. The southwest and northern part of the irrigation district have the high hydraulic gradient, such as Dongzhuang Village, Chengyu Village and Xiazhuang Village in the west and Guantun Village and Jinzhuang Village in the north. The groundwater depression cone increased to 109 km² and the boundary is 66 m. In this period, the center of the groundwater depression cone changed to Xiazhuang Village.

In 2005, the groundwater level in the most parts of the irrigation district was about 67 m. The high groundwater level areas were mostly distributed in the southwest of the irrigation district, with the highest groundwater level of 81.6 m; the low groundwater level areas were mostly distributed in the northeast of the irrigation district, with the lowest groundwater level of 60.3 m. The water table contour concentrated areas were mostly distributed near Chengyu Village, Kangcun Village and Liudi Village – the west of the irrigation district as well as Liuzhuang Village and Jinzhuang Village – the north of the irrigation district. The groundwater depression cone increased to 123 km², with a boundary of 69 m, and its center is still near Xiazhuang Village.

In 2010, the groundwater level in the most parts of the irrigation district was about 66 m. The high groundwater level areas were mostly distributed in the southwest of the irrigation district, with the highest groundwater level of 80.9 m; the low groundwater level areas were mostly distributed in the northeast of the irrigation district, with the lowest groundwater level of 58.4 m. The water table contour concentrated areas were mostly distributed near Liudi Village and Kang Village – the west of the irrigation district as well as Lihengtun Village and Zhaozhuang Village – the north of the irrigation district, and formed a groundwater depression cone with an area of 186 km² and a boundary of 67 m, and its center is still near Xiazhuang Village.

### *3.2. Driving factors of the evolution of groundwater level*

#### *3.2.1. Influence of precipitation change on the groundwater level*

As an important recharge source of groundwater, precipitation affects the groundwater level. The change of the groundwater depth in the irrigation district with precipitation in 1993–2013 is shown in Fig. 3. There is a negative correlation between the two factors, with a correlation coefficient of –0.2960, which means the groundwater level increased with the increase of precipitation. After 1993, the average precipitation was 775.8 mm/annum, the precipitation increased (or decreased) by 100 mm, and the groundwater level rose (or fell) about 0.3 m.

The increase or decrease of precipitation resulted in a change in infiltration recharge quantity of the groundwater, thereby causing fluctuation of groundwater level [21]. To reflect the relationship between the inter-annual variation trend of precipitation and the groundwater depth, the relationship between the groundwater depth and precipitation anomaly percentage was analyzed, as shown in Fig. 4. In 1993–2002, the groundwater level in the irrigation district was greatly affected by precipitation, as the groundwater level increased with the increase of precipitation, and decreased with the decrease of precipitation. In 2003–2007, the regularity of the change of groundwater level with the change of precipitation reduced with a lag, as after 2007 the groundwater depth showed a stable downward trend, and basically did not change with the change of precipitation. Fig. 4 also showed that there was a certain alternation of wet years and dry years in 1993–2013. In wet years and dry years, the groundwater level was strongly affected by precipitation, but the sensitivity of groundwater level to precipitation change was different around 2003. Before 2003, 1996, 1998 and 2000 were wet years, in which the groundwater level increased compared with the year earlier; 1997 and 2002 were dry years, in which the groundwater level decreased compared with the year earlier; 2003 was a wet year, in which the groundwater level decreased compared with 2002, but the decrease rate slowed to be 0.46 m/annum; after 2003, the change of groundwater level with the change of precipitation lagged. For example, 2007 was a dry year, but the groundwater level remained almost unchanged compared with the year earlier. While 2008 was wetter than 2007 as precipitation increased by 163.9 mm, the groundwater level decreased by 1.24 m compared with the year earlier, but increased after 2008.

### 3.2.2. *Influence of irrigation water quantity change of the canal system on the groundwater level*

Yellow River irrigation was an important irrigation way for agricultural production in People's Victory Canal Irrigation District. The relationship between the groundwater depth and the irrigation water quantity of the canal is shown in Fig. 5. There was a negative correlation between the two, and the correlation was significant with a correlation coefficient of –0.7048. The groundwater level increased with the increase of irrigation water quantity of the canal; specifically, the groundwater level increased (or decreased) by about 0.14 m with each 10,000,000 $m^3$ increase (or decrease) of irrigation water quantity of the canal. In 1993–2013, the irrigation water quantity of the canal showed a downward trend, as shown in Fig. 6. On one hand, to meet the demand for irrigation, the mining quantity of groundwater increased; on the other hand, the decrease of irrigation water quantity of the canal led to the decrease of infiltration recharge to the aquifer. The two together affected the change of groundwater level. Through the comparison between the groundwater depth and the anomaly percentage of irrigation water quantity of the canal (Fig. 6), with the increasing of canal irrigation water after 2001, groundwater level increased correspondingly. Before the year of 2001, the relationship between canal irrigation water and groundwater

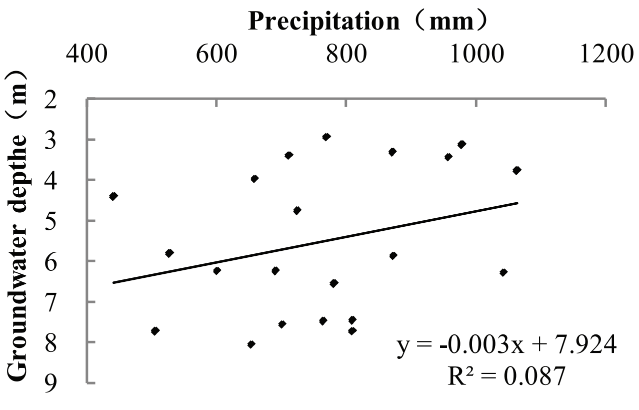


Fig. 3. Relationship between precipitation and groundwater depth.

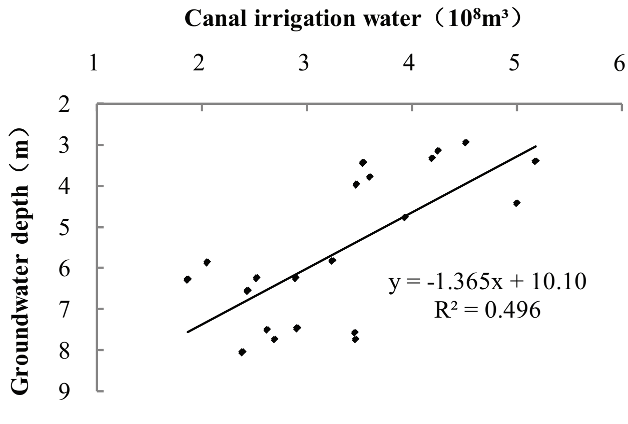


Fig. 5. Relationship between canal irrigation water and groundwater depth.

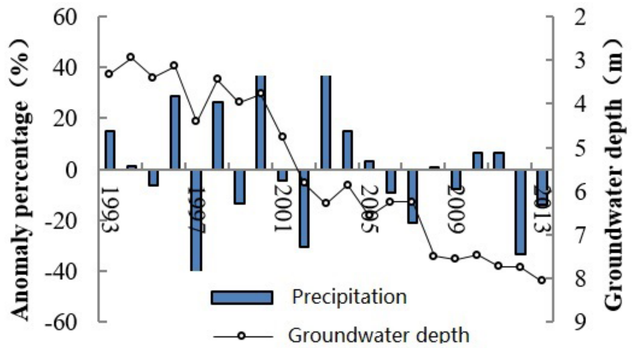


Fig. 4. Comparison between anomaly percentage of precipitation and groundwater depth.

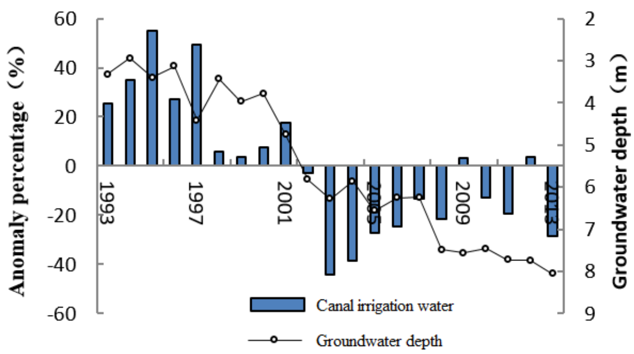


Fig. 6. Comparison between canal irrigation water anomaly percentage and groundwater depth.

level was found to be insignificant, due to the small groundwater depth, which is less than 5 m.

*3.2.3. Influence of the change of groundwater exploitation on the groundwater level*

Artificial mining was the main drainage of groundwater system in the irrigation district, and the artificial mining quantity of groundwater was mainly used for agricultural irrigation, as well as domestic and industrial.

The relationship between the groundwater depth and the irrigation water quantity of wells is shown in Fig. 7. There was a positive correlation between the two, and the correlation was significant with a correlation coefficient of 0.8058.

Through the comparison between the groundwater depth and the anomaly percentage of irrigation water quantity of wells (Fig. 8), the irrigation water quantity of wells was small in 1993–2000, while the groundwater level was high on the contrary. In 2004–2013, the irrigation water quantity of wells was large, while the groundwater level was low. And in 2001–2003, the irrigation water quantity of wells was less than that in later stage, however, with the increase of domestic and industrial water consumption, a large amount of groundwater was mined to ease the tension of domestic and industrial water, so that the groundwater level showed a marked downward trend. Meanwhile, the overall change of groundwater level with the change of irrigation water quantity of wells lagged due to the influence of precipitation, irrigation water quantity recharge on the groundwater level. For example, in 1995 the irrigation water quantity of wells decreased by 0.075 billion $m^3$ compared with the year earlier, but the groundwater level decreased by 0.46 m compared with 1994. Similarly, in 2004 the irrigation water quantity of wells increased by 0.028 billion $m^3$ compared with the year earlier, but the groundwater level increased by 0.41 m compared with the year earlier.

The relationship between the groundwater depth and domestic and industrial water consumption is shown in Fig. 9. There was a positive correlation between the two, and the correlation was significant with a correlation coefficient of 0.5495.

Through the comparison between the groundwater depth and the anomaly percentage of domestic and industrial water consumption in 1993–2013 (Fig. 10), on the whole, the groundwater level decreased with the increase of domestic

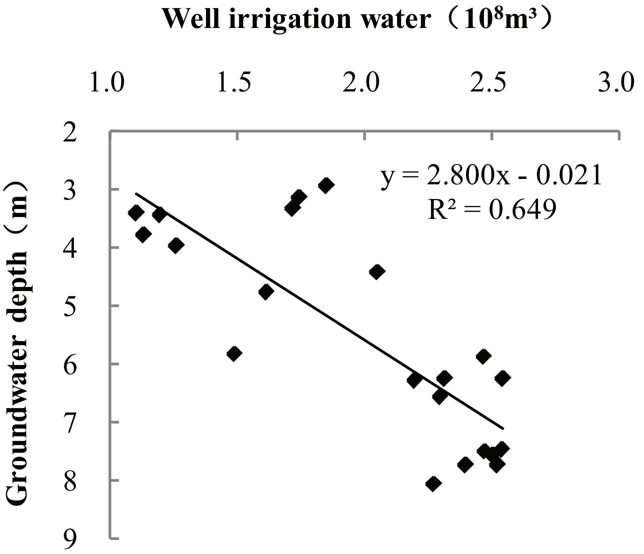


Fig. 7. Relationship between the irrigation water quantity of wells and the groundwater depth.

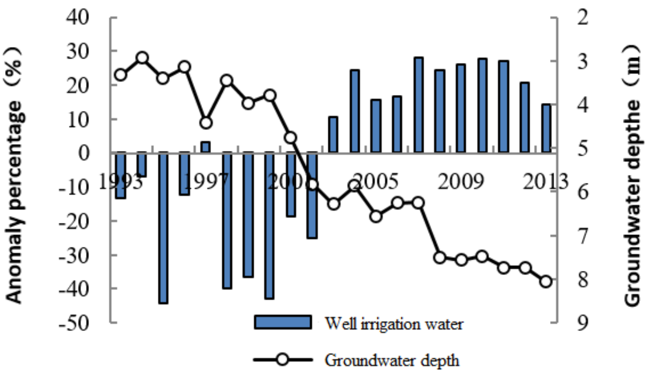


Fig. 8. Comparison between the anomaly percentage of irrigation water quantity of wells and the groundwater depth.

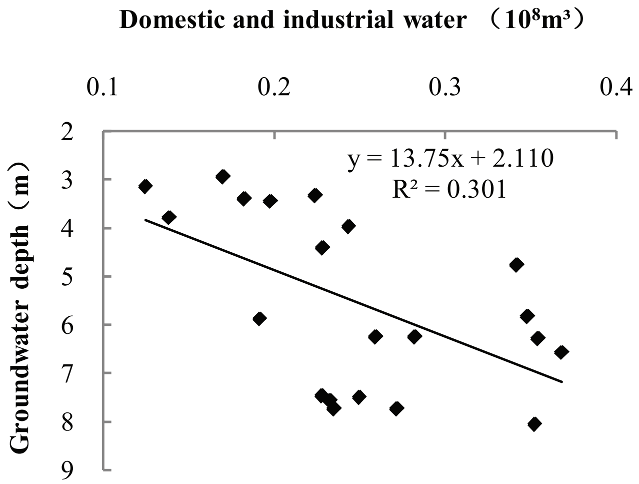


Fig. 9. Relationship between domestic and industrial water consumption and the groundwater depth.

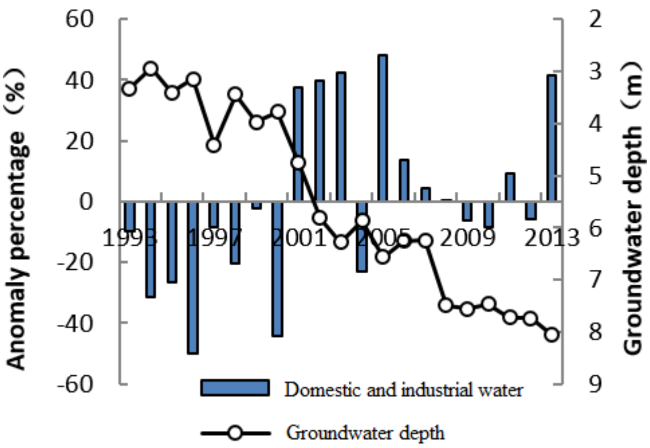


Fig. 10. Comparison between the anomaly percentage of domestic and industrial water consumption and the groundwater depth.

and industrial water consumption. For example, before 2000, the domestic and industrial water consumption was small, while the groundwater depth was also small; after 2000, the domestic and industrial water consumption was large, while the groundwater depth increased. In 1996, 2000 and 2004 in which the domestic and industrial water consumption was small, the groundwater level rose compared with the year earlier; in 2001, 2003 and 2005 in which the water consumption was large, the groundwater level correspondingly dropped. It showed that the groundwater level fluctuated obviously due to the influence of domestic and industrial water consumption, which even plummeted in 2001–2003 due to the continued increase of domestic and industrial water consumption. Combining with the actual investigation, there were two reasons: on the one hand, because there were many local chemical plants, paper mills and other high water-consuming factories, a lot of groundwater needed to be mined for industrial production; on the other hand, with the decrease in quantity of water diverted from the Yellow River and the increase in cost for using water from the canal, the majority of the local residents still chose the groundwater as the main source of domestic water.

Combined well irrigation water and domestic and industrial water, the groundwater level decreased (or increased) by 0.28 m with each 10,000,000 $m^3$ increase (or decrease) of the total groundwater consumption.

#### 3.2.4. Influence of crop planting area change on the groundwater level

The irrigated district was mainly planted cultivated crops including winter wheat and summer maize that could be harvested for two times per year. The areas in the southwest of the irrigated district, where the irrigation using water diverted from the Yellow River was convenient and the groundwater depth was shallow, were also planted with rice. In addition, the irrigated district was planted with small areas of cash crops, such as peanut, cotton and oilseed. The main cultivated crops including winter wheat, summer maize and rice belonged to the high water-consuming grain crops. People's Victory Canal Irrigation District, as an important grain production base in Henan Province, the stable and increased production of grain requires the full guarantee of irrigation water quantity, therefore, the change of groundwater level was closely related to the change of planting scale [22–25]. The change of crop planting area in the irrigated district showed a downward trend, and the downward trend was obvious, as shown in Fig. 11.

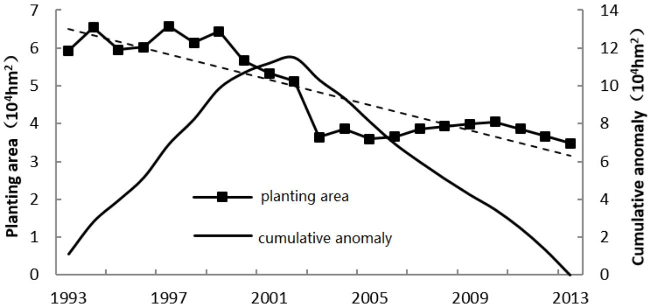


Fig. 11. Curves of planting area and cumulative anomaly.

The change of the planting area of main cultivated crops in the irrigated district was divided into two stages. The first stage was before 2002, the planting area of main cultivated crops was large. And the second stage was after 2002, the planting area of main cultivated crops was small. Before 2002, the planting area of main cultivated crops showed positive anomaly, in 1996, the planting area increased to 64,400 ha, an increase of 16,200 ha from the mean annual planting area. After 2002, the planting area of main cultivated crops showed negative anomaly, in 2003, the planting area decreased to 36,400 ha, a decrease of 11,900 ha from the mean annual planting area.

Through the field visit and analysis of questionnaire survey results, because of the ageing of agricultural infrastructure, low utilization coefficient of canal water and insufficient water expenditure, few areas in the irrigation district diverted water from the Yellow River for irrigation, and most areas used the groundwater to supplement irrigation. In other words, although the planting area was reduced, the area of well irrigation water transformed from canal irrigation increased, and the proportion of well irrigation quantity to total irrigation water quantity increased, which led to a decrease in groundwater level.

### 3.3. Analysis of the dominant driving factors of the evolution of groundwater level

According to the analysis results of the effects of climate change and human activities on the groundwater, the dominant driving factors of the evolution of groundwater level were determined using grey relational analysis with the precipitation ($Z_1$), irrigation water quantity of the canal ($Z_2$), irrigation water quantity of wells ($Z_3$), domestic and industrial water consumption ($Z_4$) and the planting area of main cultivated crops ($Z_5$) as the driving factors of the variation of groundwater level.

Tables 1 and 2, respectively, reflect the calculated results of correlation coefficient and correlation degree $r_{ok}$. The correlation degree was ordered in descending order as follows: irrigation water quantity of wells, domestic and industrial water consumption, precipitation, irrigation water quantity of the canal, and planting area of main cultivated crops. It showed that the influence of irrigation water quantity of wells on the groundwater level was the strongest, followed by the domestic and industrial water consumption. Through the field visits and investigations, it was found out that most of local residents still used the well water for irrigation and living, and large chemical enterprises used the groundwater as the main source of production water, which showed that the groundwater depth was greatly affected by the artificial mining quantity of underground water.

Thus, in recent years human activities played a dominant role in the variation of groundwater. Development and increase of economy and population in recent years, as well as more and more areas used the well irrigation for agricultural irrigation production, lead to a sharp increase in the mining quantity of groundwater. That is to say, due to increase of irrigation and domestic and industrial water consumption, the discharge quantity of groundwater increased, and the groundwater level showed an obvious downward trend. Although the influence of precipitation and irrigation

Table 1
Calculated results of correlation coefficient

| $\xi_{01}(i)$ | $\xi_{02}(i)$ | $\xi_{03}(i)$ | $\xi_{04}(i)$ | $\xi_{05}(i)$ |
|---|---|---|---|---|
| 0.466 | 0.423 | 0.646 | 0.616 | 0.432 |
| 0.498 | 0.368 | 0.544 | 0.763 | 0.366 |
| 0.598 | 0.337 | 0.901 | 0.806 | 0.435 |
| 0.398 | 0.404 | 0.608 | 0.886 | 0.412 |
| 0.693 | 0.406 | 0.673 | 0.805 | 0.458 |
| 0.427 | 0.523 | 0.973 | 0.737 | 0.423 |
| 0.765 | 0.600 | 0.864 | 0.649 | 0.436 |
| 0.399 | 0.549 | 0.818 | 0.799 | 0.493 |
| 0.843 | 0.604 | 0.918 | 0.482 | 0.666 |
| 0.575 | 0.862 | 0.615 | 0.580 | 0.990 |
| 0.670 | 0.453 | 0.952 | 0.625 | 0.557 |
| 0.849 | 0.518 | 0.728 | 0.624 | 0.651 |
| 0.759 | 0.512 | 0.953 | 0.621 | 0.522 |
| 0.689 | 0.561 | 0.937 | 1.000 | 0.564 |
| 0.588 | 0.647 | 0.762 | 0.855 | 0.595 |
| 0.581 | 0.456 | 0.821 | 0.579 | 0.470 |
| 0.520 | 0.591 | 0.826 | 0.527 | 0.469 |
| 0.631 | 0.500 | 0.880 | 0.525 | 0.484 |

Table 2
Calculated results of correlation degree

| | |
|---|---|
| $r_{01}$ | 0.590 |
| $r_{02}$ | 0.511 |
| $r_{03}$ | 0.788 |
| $r_{04}$ | 0.692 |
| $r_{05}$ | 0.509 |

water quantity of the canal on the groundwater level was not very strong, in the light of the decreasing trend, they resulted in a decrease in groundwater recharge, which led to a further reduction in groundwater resources.

## 4. Conclusion

In terms of meteorological factors, the groundwater level was affected by precipitation, as the groundwater level rose (or fell) by about 0.3 m when the precipitation increased (or decreased) by 100 mm. In terms of human activities, the groundwater level was obviously affected by the irrigation water quantity of the canal, irrigation water quantity of wells, domestic and industrial water consumption, and planting area of main cultivated crops. The groundwater level rose (or fell) by 0.14 m when the irrigation water quantity of the canal increased (or decreased) by 10,000,000 $m^3$, and the groundwater level fell (or rose) by 0.28 m with each 1,000,000 $m^3$ increase (or decrease) of irrigation water quantity of wells, and the groundwater level fell (or rose) by 0.14 m with each 1,000,000 $m^3$ increase (or decrease) of domestic and industrial water consumption.

Before 2001, there were much irrigation water quantity of the canal, little irrigation water quantity of wells, and little domestic and industrial water consumption, so the groundwater depth was small. However, after 2001, with the decrease of irrigation water quantity of the canal diverted from the Yellow River, the irrigation water quantity of wells increased, and the domestic and industrial water consumption also increased obviously, so the groundwater level dropped rapidly.

The correlation degree between the groundwater level and its various influencing factors was calculated using grey relational analysis. The correlation degree was ordered in descending order as follows: irrigation water quantity of wells, domestic and industrial water consumption, precipitation, irrigation water quantity of the canal, and planting area of main cultivated crops.

## Acknowledgements

This study was supported by the Plan for Scientific Innovation Talent of Henan Province in China (Grant No. 144100510014), the "948" Program of the Ministry of Water Resources in China (Grant No. 201328), the National Natural Science Foundation of China (Grant No. 51209090), the National key Research and Development Program of China (Grant No. 2016YFC0401400).

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