DIFFERENT EVOLVING CHARACTERISTICS AND MECHANISM OF THE INFLUENCE ON THE GROUNDWATER DEPTHS FROM EXPLOITATION IN THE TYPICAL REGION OF NORTH CHINA PLAIN

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Abstract. There is a significant time-dependent differentiation in the relationship between groundwater depth and groundwater exploitation in the North China Plain. In order to further understand the evolving pattern of the groundwater system, the double-cumulative curve method was used to analyze the changes in the groundwater depth in relation to the amount of groundwater exploited. The mechanism was analyzed from the perspective of groundwater balance, and the leading factor influencing the change in groundwater levels was revealed. The degree of differentiation in terms of the influence of the amount of water exploited on the groundwater depth was calculated using the water balance equation, a statistical method, and a derivative method. The conclusions include the following. In 1982, in the Shijiazhuang Plain, the evolving pattern of the groundwater depth with exploitation significantly changed. Before 1982, the increase in the exploitation amount was the main reason for the increase in the groundwater depth. After 1982, there was a continuous slight increase in the exploitation amount and a simultaneous obvious reduction in the supply amount, and they exacerbated the negative water balance in the groundwater system in relation to both inflow and outflow. Before 1982, the groundwater level was decreasing at a rate of 0.29 m in relation to a groundwater exploitation amount of 1×10^8 m^3. However, after 1982, the groundwater level decreased at a rate of 1.25 m for the same amount of exploitation. This was a reinforcement of the influence of exploitation on the groundwater depth. It is considered that a clear understanding of the evolving mechanisms in terms of the influence of groundwater exploitation on the groundwater depth in the North China Plain is of great importance, and is required to develop plans involving the reasonable use and conservation of regional groundwater resources.
Keywords: *groundwater overexploitation; double-cumulative curve; groundwater evolution; different evolving mechanism; degree of different evolution*

Introduction

North China Plain (NCP) is the region bordered on the east by Bohai Sea, on the west by the Taihang Mountain, on the north by Yanshan Mountain, and on the south by Yellow River. This region includes all the plains of Hebei Province, Beijing and Tianjin, and the northern parts of the plains in Shandong and Henan Provinces. It covers an area of 13.92×10^4 km^2 (Zhang et al., 2011). It was in the NCP that the ancient Chinese civilization originated as a society developed from agriculture and has since flourished for more than 4000 years (Liu et al., 2008). Today, the NCP remains the most important economic and political center of China. However, along with other areas in the country, it suffers from a shortage of water resources (Zhang et al., 2011; Shao et al., 2009). Groundwater accounts for 70% of the total water supply in this area, but a number of

serious environmental and resource problems have emerged in relation to long-term over-exploitation, such as the exhaustion of groundwater resources and land subsidence, which are seriously affecting the safety of water supply in the area (Shao et al., 2009; Wang et al., 2008).

There has been a significant decrease in the shallow groundwater level within the North China Plain, in particular in the plain areas facing the Taihang Mountains. Some areas have experienced an average annual water level decrease of one meter, and this noticeable change is receiving both national and international attention (Veit and Conrad, 2016; Sahoo and Jha, 2015). In this respect, more and more studies have analyzed the evolution of the groundwater system and its leading influencing factors in the North China Plain. Zhang et al. (1997) used the gray correlation method to explore the influence of precipitation and groundwater exploitation on the dynamics of groundwater environmental evolution. Jia and Liu (2002) prepared an X-shaped curve to present the relationship between food production and the average groundwater level, based on materials from 1947 to 2000. Using a projection pursuit regression model, Xu et al. (2003) quantitatively evaluated the influence of precipitation, temperature, surface runoff, and groundwater exploitation on the decrease in groundwater level, and determined the relative contribution rate of each factor on the decrease in the groundwater level. Zhang et al. (2006a) analyzed the dynamic changing patterns of agricultural exploitation of groundwater, groundwater recharge, and the groundwater level in the Hebei Plain (south of Beijing and Tianjin), and showed that a bipolar reciprocal effect existed between exploitation and precipitation. Using the Hebei plain area (south of Beijing and Tianjin) as an example, Fei (2006) analyzed the evolutionary characteristics of the groundwater system, and revealed the influence of precipitation infiltration, water project retention, surface runoff change, and exploitation on the level of groundwater. These existing studies have provided a good foundation for understanding the evolving characteristics and mechanisms involved in the groundwater system in the North China Plain. However, the evolution of the groundwater system in this area has suffered from an obvious time-dependent effects and a significant change characteristics. In addition, the influence of each factor on the groundwater level is not constant over time (Arora, 2002; Shahabeddin et al., 2011). But limited studies have been conducted pertaining to identify these time nodes or determine influencing degree of different segments of time in relation to the influence of exploitation on groundwater depth (Konkul et al., 2014).

Taking Shijiazhuang Plain as a case, this study analyses the changing characteristics of groundwater depth and exploitation quantity since the 1950s. Using water balance equation and statistical methods, the differentiation characteristics, differentiation mechanisms, and differentiation degrees are revealed in relation to the influence of the exploitation amount on the groundwater depth. It is considered that the results presented in this study provide a scientific understanding of the evolution of the groundwater system, and could thus be used to promote reasonable utilization and conservation of the groundwater resources in the North China Plain.

Materials and methods

Study area

The Shijiazhuang Plain is located at E114°17′–115°22′; N37°02′–38°03′, and is a part of the Hutuo River alluvial-proluvial fan. The Taihang Mountains lie to its west, and the

central plain of Hebei lies to its east. The plain encompasses one city and 11 counties, including Shijiazhuang, Zhengding, Luancheng, Xingtang, Gaoyi, Shenze, Wuji, Yuanshi, Zhaoxian, Gaocheng, Jinzhou and Xinle. It covers an area of 6,673 km^2 with a population of 4.787 million, and of which, 3.852 million people depend on the agricultural industry for their livelihoods.

The Shijiazhuang Plain has a continental monsoon climate, with an average annual precipitation of 496.6 mm, 70%–80% of which is usually concentrated between June and September. The area has strong surface evaporation, with an average annual evaporation of 1992 mm (Li and Xu, 1986). The downstream river runoff from the Hutuo River, which is the main river in the area, has been significantly reduced since the completion of the upstream Gangnan and Huangbizhuang Reservoirs. The river has dried up considerably since 1980, and this is reflected in the lack of river water supplying the surrounding terrain. Groundwater has thus become the predominant means of water supply to industries within the area (Liu et al., 2004). Because the Shijiazhuang Plain is distributed in the piedmont alluvial zone of the Taihang Mountains, the groundwater are main phreatic, with pressurized local areas (Zhang et al., 2006b).

Groundwater is consumed mainly via artificial exploitation and evaporation. However, with the increase in exploitation, the depth of the groundwater has increased, thereby reducing the potential for evaporation. As a result, artificial exploitation is now the main route of discharge.

Data sources

Data pertaining to the groundwater depth and its exploitation from 1956 to 2005 are used in this study, which represent monitoring data obtained from the "Hydrology and Water Resources Bureau of Hebei Province". These data are compared with those of the "Water Resource Bulletin of Hebei Province", and the "Groundwater Statistical Yearbook of Hebei Province"; thereby ensuring results with relatively high consistency and reliability.

Data pertaining to the precipitation infiltration amount, irrigation recharge amount, canal leakage amount, lateral inflow amount, and exploitation amount from 1976 to 2005 (the total amount of every 5 years) are also used in this study, and were obtained from the Geological Environment Monitoring Station of Hebei Province. These data are compared with the results of regional groundwater resource evaluation from the 1956–1984 and 1991–2003, and as such, it is considered that the results presented in relation to the data used have relatively high consistency and reliability.

Method used to recognize evolving differentiation

The double-cumulative curve (DCC) method is used to identify the time nodes in relation to the evolving patterns of differentiation of the influence of exploitation on the groundwater depth. The DCC method is often used in time series analysis. In this study, the basic idea was to estimate the annual groundwater depth, which is accumulated gradually, together with the corresponding annual amount of groundwater exploitation. The double-cumulative curve of the depth-exploitation points within the studied time period was then plotted, with one of the two variables representing the horizontal and vertical ordinates, respectively. The points of inflection (on the curve) thus represented evidence of the stage changes of the variables analyzed. The double cumulative curve of

depth vs. exploitation is normally used to determine if groundwater depth shows any changing trends. The objective of this study is to decipher a changing pattern in groundwater depth with reference to the exploitation amount. Therefore, the cumulative amount of groundwater exploitation is used as the horizontal ordinate, and the cumulative groundwater depth is used as the vertical ordinate when plotting the double cumulative curve.

Discrimination method to determine the degree of differentiation

The influence of groundwater exploitation on groundwater depth has a time-dependent differentiation, and the degree of influence differs within various stages before and after a time node (Mackay, 2015; Sanderson and Curtis, 2016; Serrano et al., 2016; Shanley et al., 2016; Serrano, L. et al., 2016). The choice of method used to determine the degree of differentiation in the relationship between the exploitation amount and groundwater depth is a key issue in the study of groundwater system evolution on the North China Plain (Dooge et al., 1999; Niemann and Eltahir, 2005; Ghoraba et al., 2013). In this respect, this study used a discrimination method based on the groundwater balance equation, and a statistical method, as follows:

(1) Discrimination Method Based on the Groundwater Balance

Based on the recognition results of evolving differentiation, it was clear that an obvious differentiation existed in the rule of groundwater depth variation with exploitation changing, and the differentiation occurred between the pre- and post-1982 periods in the study area.

1) Human activities had a relatively small influence on groundwater before 1982, and the influencing factors for the evolution of the groundwater system were relatively simple. Using theoretical analysis, it became clear that the amount of exploitation was the major factor related to the evolution of the groundwater system, and therefore it was determined that the relationship between groundwater depth and the exploitation amount could be established using regression analysis:

$$D = f(Q_e) \tag{Eq.1}$$

Where D is the groundwater depth, and Q_e is the groundwater exploitation amount.

When Q_e has a relatively small value, the changing rate of groundwater depth in relation to the change of exploitation amount can be calculated using a derivative method:

$$v = \frac{\Delta D}{\Delta Q_e} = \widehat{f_Q}(Q_e) \tag{Eq.2}$$

Where, v is the changing rate for groundwater depth with a change in the exploitation amount; ΔD is the change of groundwater depth; and ΔQ_e is the change in the amount of groundwater exploitation.

2) Since 1982, the influencing factors involved in the evolution of groundwater system have become relatively more complicated. The water-balance method can therefore be used to determine the dominant factors involved in the change in groundwater depth (Yeh et al., 2007), and the groundwater balance equations in the studied area are as follows:

$$\Delta Q = Q_r - Q_d \qquad \text{(Eq.3)}$$

$$F\mu\Delta H = Q_{pi} + Q_{ii} + Q_{si} + Q_l - Q_e \qquad \text{(Eq.4)}$$

Where ΔQ is the change in the amount of groundwater resources, Q_r is the total recharge amount of groundwater, Q_d is the total amount of groundwater discharge, F is the area of the region studied, μ is the specific yield, ΔH is the change in the groundwater level, Q_{pi} is the recharge amount from precipitation infiltration, Q_{ii} is the recharge amount from irrigation return, Q_{si} is the recharge amount from canal infiltration, and Q_l is the lateral recharge amount. The other symbols have the same meaning as previously stated above.

The results of the water balance in the studied area show that since 1982, the dominant factor for the increase in groundwater depth is the increasing negative balance status of the groundwater system. In this respect, regression analysis can be used to establish the relationship between groundwater depth and the over-exploitation amount, as follows:

$$D = f(Q_{eo}) \qquad \text{(Eq.5)}$$

Where Q_{eo} is the amount of groundwater over-exploitation.

$$v = \frac{\Delta D}{\Delta Q_{eo}} = \widetilde{f_Q}(Q_{eo}) \qquad \text{(Eq.6)}$$

Where ΔQ_{eo} is the change in the amount of groundwater over-exploitation. The other symbols have the same meaning as already stated above.

By using reduction calculation, and assuming the recharge amount of groundwater to be the same before and after 1982, the changing rate of groundwater depth with the change of exploitation amount can thus be determined.

(2) Discrimination Method Based on the use of Statistic Methods

The changing rate of groundwater depth with the change of the dominant factor can be calculated as follows:

$$D = f(Q_e, \varphi) \qquad \text{(Eq.7)}$$

Where φ represents the factors other than exploitation that affect the groundwater depth, which include precipitation infiltration, irrigation return, lateral recharge, and evaporation. The other symbols have the same meaning as already shown above.

$$\Delta D = \Delta D_{Qe} + \Delta D_{\varphi} \qquad \text{(Eq.8)}$$

Where ΔD_{Qe} is the change in groundwater depth in relation to the change in the ground water exploitation amount; and ΔD_{φ} is the change in groundwater depth in relation to other factor changes. The other symbols have the same meaning as previously stated above.

When there is no significant change in the other factors (φ), and the change in the groundwater exploitation amount is small, the change in rate of groundwater depth in

relation to the change in the exploitation amount can be calculated using the following equation:

$$v = \frac{\Delta D}{\Delta Qe} = \hat{f}_Q(Q_e, \varphi) \tag{Eq.9}$$

Where all the symbols presented here have the same meanings as previously shown above.

Results and discussion

Variation in groundwater exploitation and depth

Groundwater depth was between 2 m and 6 m from 1953 to 1969. Groundwater level increased or decreased (*Fig.1*). The average groundwater exploitation was 9.88×10^8 m^3, but it increased from 3.59×10^8 m^3 in 1954 to 17.60×10^8 m^3 in 1969. Accordingly, groundwater depth increased from 2.27 m to 5.56 m, and groundwater level dropped by an average of 0.15 m per year.
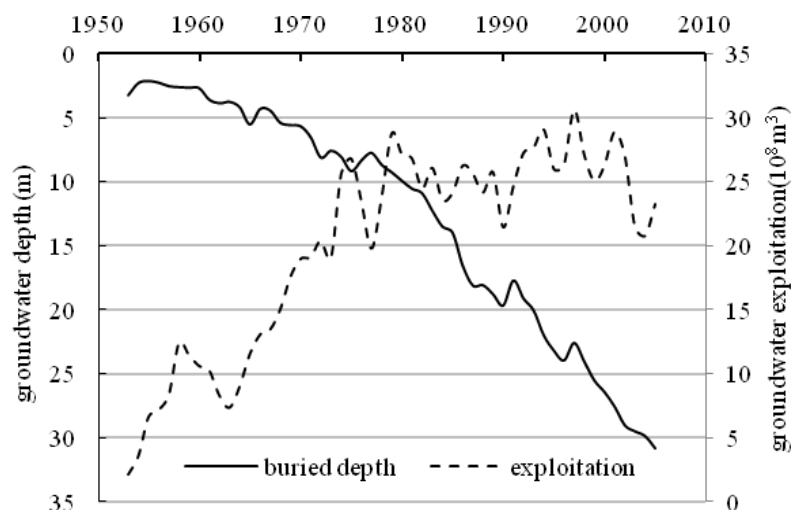

Figure 1. Dynamic curve of groundwater exploitation and depth

Groundwater depth was between 5 m and 9 m from 1970 to 1979. In wet years (i.e., 1976 and 1977), groundwater level still increased. Groundwater exploitation continuously increased from 23.81×10^8 m^3 in 1978 to 28.83×10^8 m^3 in 1979, with an average exploitation of 22.62×10^8 m^3. Groundwater level decreased by an average of 0.37 m per year.

Groundwater depth was between 10 m and 30 m after 1980, but it increased more obviously, i.e., approximately 0.83 m per year on average. Groundwater level rose except in special wet years (i.e., 1990 and 1996). In other wet years (i.e., 1992 and 1995), groundwater level continued to decline, although the decrease was more gradual. Between 2000 and 2005, groundwater exploitation was reduced. Mean exploitation was recorded at 24.66×10^8 m^3, which was smaller than 26.57×10^8 m^3 in the 1990s. However, groundwater level still obviously dropped at a rate of 0.74 m per year.

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Different characteristics of the influences of groundwater exploitation on depth

Exploitation is the major source of discharge for the groundwater system, and any changes in this amount therefore affect the level of groundwater (the relationship is shown in *Fig. 2*). Between the 1950s and 1970s, groundwater depth increased with an increase in the exploitation amount, and the relationship between the two was nearly linear. However, from the beginning of the early 1980s, the relationship between the two significantly deviated from being linear, and all the points recorded were below those of the straight line.
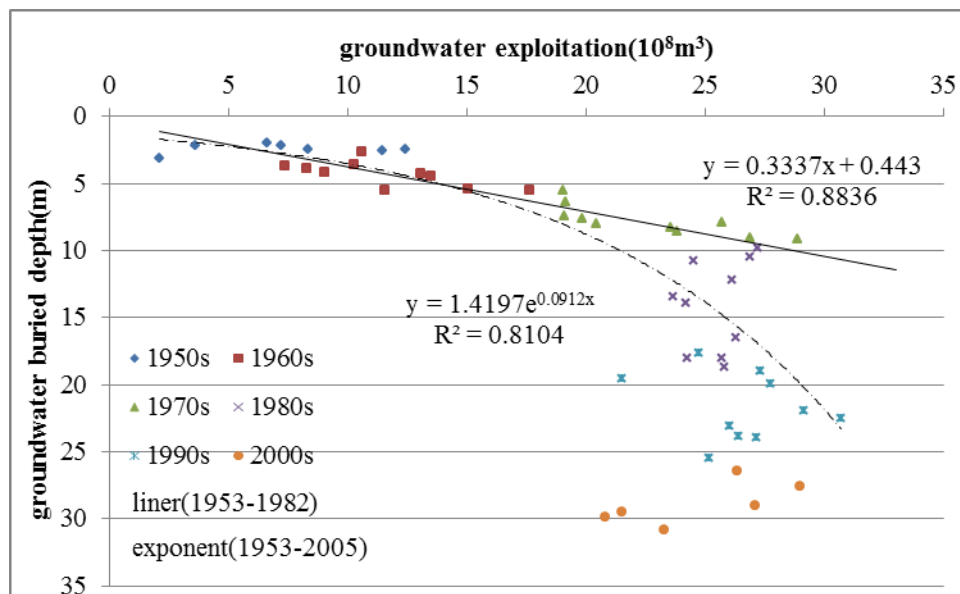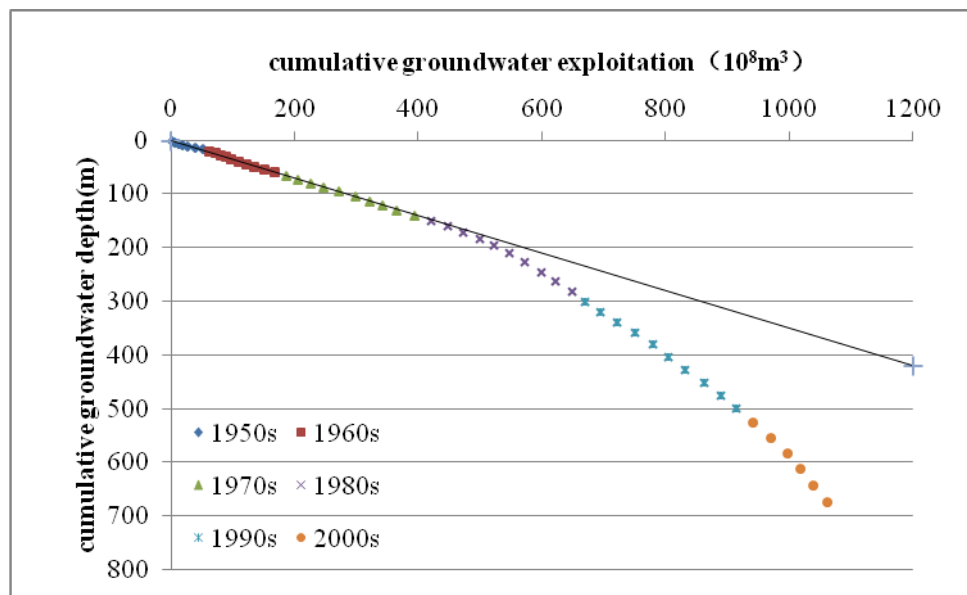

Figure 2. *Relationship between groundwater exploitation and depth*

Prior to 1982, a relatively small amount of groundwater exploitation occurred, with an average of 16×10^8 m^3 from 1951 to 1982. As a result, groundwater depthwas also relatively shallow, and was at a height of 10 m around the year 1982. During this period, the groundwater depth began to increase with an increase in the exploitation amount. However, because the total exploitation amount was relatively small, the change in groundwater depthwas insignificant, with an average annual increase of about 0.27 m.

After 1982, the data points referring to the relationship between the exploitation amount of the groundwater and depth are seen to be situated below the straight line established using data prior to 1982. This means that although the increase in the exploitation amount was the same, there was a larger decrease in the groundwater level after 1982 than before this year. Furthermore, the amount of groundwater exploitation fluctuated between 21 and 30×10^8 m^3, with an average amount of 25.6×10^8 m^3 after 1982, which is 1.6 times the average amount prior to this date. By 2005, the groundwater depth had increased from a value of 10.9 m in 1982, to 30.87 m. In this respect, there was an annual average groundwater level decrease of 0.83 m, which is 3.1 times that which occurred prior to 1981.

The double-cumulative curve showing the relationship between the amount of groundwater exploitation and depth is shown in *Fig. 3*. It is evident that there was a significant increase in the cumulative depth of groundwater in relationship to the

increase in cumulative groundwater exploitation. Before 1982, the relationship between the two was obviously linear, but after this, the data points begin to deviate; they are all located below the straight line. As shown in *Fig. 3*, differentiation began in 1982 in relation to the influence of groundwater exploitation on the groundwater depth, and after this, the amount of exploitation had an increasingly intensified influence on the groundwater level. It also means when all other conditions remained the same as before 1982, the ability of the groundwater system to support the amount of water being exploited decreased significantly after 1982.

Figure 3. *Relationship between cumulative groundwater exploitation and the cumulative depth of groundwater*

Differentiation mechanism involved in the influence of exploitation on groundwater depth

From a water balance perspective, the evolution of a groundwater system indicates a joint action between recharge and discharge items. In 1982, there was a significant difference in the changing pattern of groundwater depthin relation to a change in exploitation. The fundamental reason for this is that the groundwater system significantly changed in around the year 1982. This study therefore analyzes the recharge and discharge variation in the groundwater system of the study area, and determines the reason for the different evolution in the groundwater system.

The study area is the pediment alluvial plain of Taihang Mountains, and the recharge items for the groundwater system mainly include precipitation infiltration, canal leakage, lateral recharge from the front of the Taihang Mountains, and irrigation returns. The groundwater in the studied area is situated at a relatively large depth (greater than 10 m from 1981, and 20 m after the 1993). In this respect, the evaporation amount is small and negligible, and exploitation is therefore the main discharge item for the groundwater system.

The data on the balance of the groundwater in the studied area in relation to groundwater recharge items and discharge items was compiled, and the results are shown over periods of five years in *Table 1*.

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Table 1. *Characteristics of the groundwater balance items ($10^8 m^3$)*

	Precipitation Infiltration	Irrigation Return	Canal Leakage	Lateral Recharge	Exploitation	ΔQ
1976–1980	50.99	30.27	19.43	22.00	123.19	-0.50
1981–1985	60.53	31.60	9.22	20.02	125.29	-3.91
1986–1990	43.18	14.48	7.31	20.45	123.44	-38.01
1991–1995	38.29	12.13	13.34	13.53	134.89	-57.60
1996–2000	42.34	16.38	24.86	13.13	135.68	-38.96
2001–2005	37.75	6.18	12.52	7.82	121.60	-57.34

According to groundwater exploitation variation characteristics and the results shown in the table above, there was a significant increasing trend in the amount of groundwater exploitation in the period before the early 1980s, which increased from 46.48×10^8 m^3 in 1961–1965 to 123.19×10^8 m^3 in 1976–1980. After the early 1980s, the increase in groundwater exploitation slowed down, and reached an amount of 135.68×10^8 m^3 from 1996–2000. There was thus a reduced amount of groundwater being exploited in the beginning of the 21st century.

There was little change in the groundwater recharge items during the periods 1976–1980 and 1981–1985 (122.69×10^8 m^3 and 121.38×10^8 m^3, respectively). However, after the early 1980s there was a significant reduction in the comprehensive recharge amount; 85.43×10^8 m^3 in the period of 1986–1990, which was 30.37% less than that in 1976–1980.

From the results of the balance calculation, it can be seen that the groundwater system in the studied area was in a state of negative balance that first appeared in 1976–1980, and thereafter the degree of negative balance continued to increase. The recharge-discharge differences were -0.50×10^8 m^3 in 1976–1980, -3.91×10^8 m^3 in 1981–1985, -38.01×10^8 m^3 in 1986–1990, -57.6×10^8 m^3 in 1991-1995, -38.96×10^8 m^3 from 1996–2000, and -57.34×10^8 m^3 in 2001–2005.

In summary, there was a significant intensification in the degree of negative balance in the groundwater system, beginning in the early 1980s. The pattern of changes in groundwater depthin relation to agricultural exploitation also differed significantly. The two had an obvious correlation, and the change in the balance results reflected the change in groundwater depth. Before the early 1980s, the change of groundwater recharge was small while the exploitation amount continued to increase, and the groundwater system had a slightly negative balance until the period 1976–1980. Therefore, the increase in groundwater exploitation was the fundamental reason for the decrease in the groundwater level. After the early 1980s, the amount of groundwater exploitation was maintained at a relatively high level, but the recharge amount significantly decreased, which intensified the negative balance status of the groundwater system. That is, after the 1980s, the high level of groundwater exploitation and the decrease in the groundwater recharge worked in tandem to accelerate the decline in the groundwater level. In the 21st century, the decline in the groundwater level has led to a series of hydrogeological and environmental-geological problems, which have gradually attracted attention. There has been a limited reduction in the amount of groundwater exploited and the comprehensive recharge amount to the groundwater system is continuing to decrease significantly. Therefore, the groundwater level continues to decline.

Discrimination of the differentiation degree based on groundwater balance

According to *Fig. 2*, the linear fitting relationship between the groundwater exploitation amount (Q) and the groundwater depth (h) before 1982 was $h = 0.32Q + 0.54 (R^2 = 0.88)$. This means that before 1982, with every increase in groundwater exploitation of 1×10^8 m^3, there was a decline of 0.32 m in the groundwater level. In this period, there was an average annual decline of 0.27 m in groundwater depth per year.

Because the data points after 1982 deviate from the straight line, and are all located below the fitted line, this shows that there was an increase in the changing rate of groundwater depthin relation to a change in the exploitation amount. According to the balance results of the groundwater system, the reason for this differentiation was an intensification of the negative balance status of the groundwater after 1982, which can be represented by the over-exploitation amount (the difference between the total discharge amount and total recharge amount of the groundwater system) (Chang et al., 2015; Kaur et al., 2015). Therefore, the groundwater depth is closely related to the amount of groundwater that is over-exploited (Gholami et al., 2015; Kushwaha and Goyal, 2016).

Fig. 4 shows the relationship between the groundwater depth (h) and the over-exploitation amount (Q) after 1982. The linear fitting relationship between the two is $h = 1.34Q + 10.18 (R^2 = 0.78)$. This means that with every increase of 1×10^8 m^3 in the amount of groundwater over-exploited, there was a decline of 1.34 m in the groundwater level. Using the reduction method, and assuming that the groundwater system recharge items were the same before and after 1982, this means that with every increase in groundwater exploitation of 1×10^8 m^3 , there was a decrease of 1.34 m in the groundwater level after 1982.
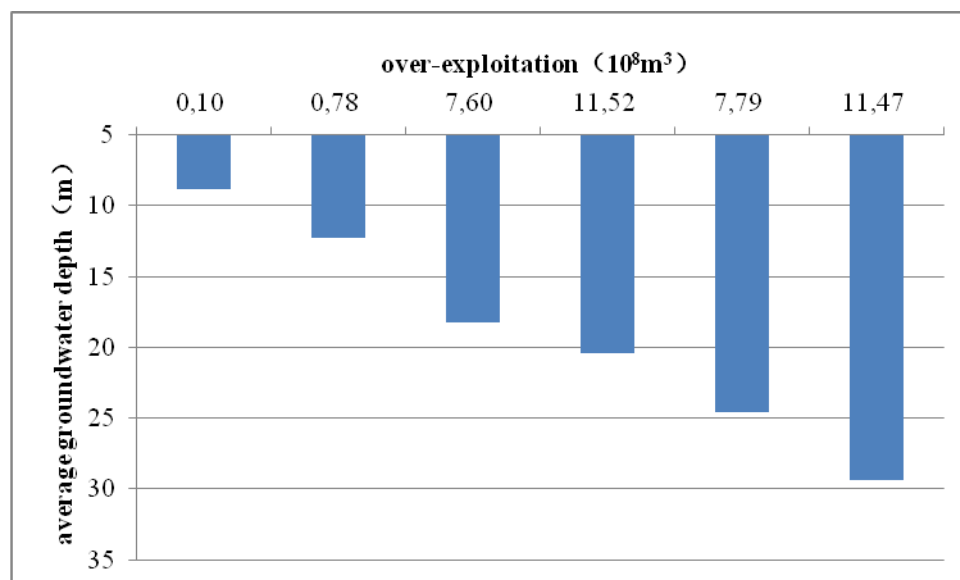
Figure 4. *The influence of the negative groundwater balance on the average depth*

Discrimination of differentiation degree using statistics

According to *Fig. 2*, the exponential fitting relationship between the groundwater exploitation amount (Q) and the groundwater depth (h) was $h = 1.4803e^{0.0875Q}$

($R^2 = 0.81$) between 1953 and 2005, which is considered to be a good fit. Therefore, in order to calculate the changing rate in groundwater depthin relation to the change in the exploitation amount, it is necessary to take the first order derivative on both sides of the exponential fitting relationship with respect to Q, to obtain $\widehat{h_p} = 0.1295e^{0.0875Q}$; where $\widehat{h_p}$ is the changing rate in groundwater depthto the change in the exploitation amount, which has two stages, i.e., before and after 1982. Before 1982, the average value for the derivative of groundwater depth to that of exploitation was 0.31. This means that for every increase in groundwater exploitation of 1×10^8 m^3, there was a 0.31 m decline in the level of groundwater. However, because the data points after 1982 significantly deviate from the fitting curve, the calculated changing rate only reflects that there was a trend in the change of the groundwater depth, with an average of about 1.15 m / (10^8 m^3). That is, with every increase of 1×10^8 m^3 in the exploitation of groundwater there was a decline of 1.15 m in the groundwater level.

In summary therefore, the linear and exponential fitting results were very close before 1982 for the changing rate in groundwater depthin relation to the change in the exploitation amount. For every increase in the exploitation of groundwater of 1×10^8 m^3, there was a decline of 0.27 m (linear fitting) and 0.31 m (exponential fitting) in the level of groundwater; the average of the two is 0.29 m. In addition, the linear and exponential fitting results for the changing rate in groundwater depthin relation to the change in the amount of exploitation after 1982 were also very close. With every increase in the amount of groundwater exploitation of 1×10^8 m^3, there was a decline of 1.15 m (linear fitting) and 1.34 m (exponential fitting) in the groundwater level, with an average value for the two of 1.25 m.

Conclusions

Based on the relationship curve between groundwater depth and the amount of exploitation, and the relationship curve between the cumulative depth of groundwater and the cumulative exploitation amount, there was a significant differentiation, which was from 1982, in the changing pattern in the groundwater level in relation to the changing amount of exploitation in Shijiazhuang Plain since 1950s.

Before 1982, the increase in the exploitation amount was the dominant factor for the increase in the groundwater depth. After 1982, the continuously high exploitation amount, and the decrease in the recharge amount intensified the negative balance status of the groundwater system in relation to both recharge and discharge, and this was the main reason for the continuous, or accelerated, decline in the groundwater level.

Based on statistics and the balance result for the groundwater system, there was a decline of 0.29 m in the groundwater level for every increase of 1×10^8 m^3 in the groundwater exploitation before 1982. After 1982, this number expanded to a 1.25 m decline in the groundwater level for the same amount of exploitation. The influence of the exploitation increase on the groundwater depth was therefore more and more larger.

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